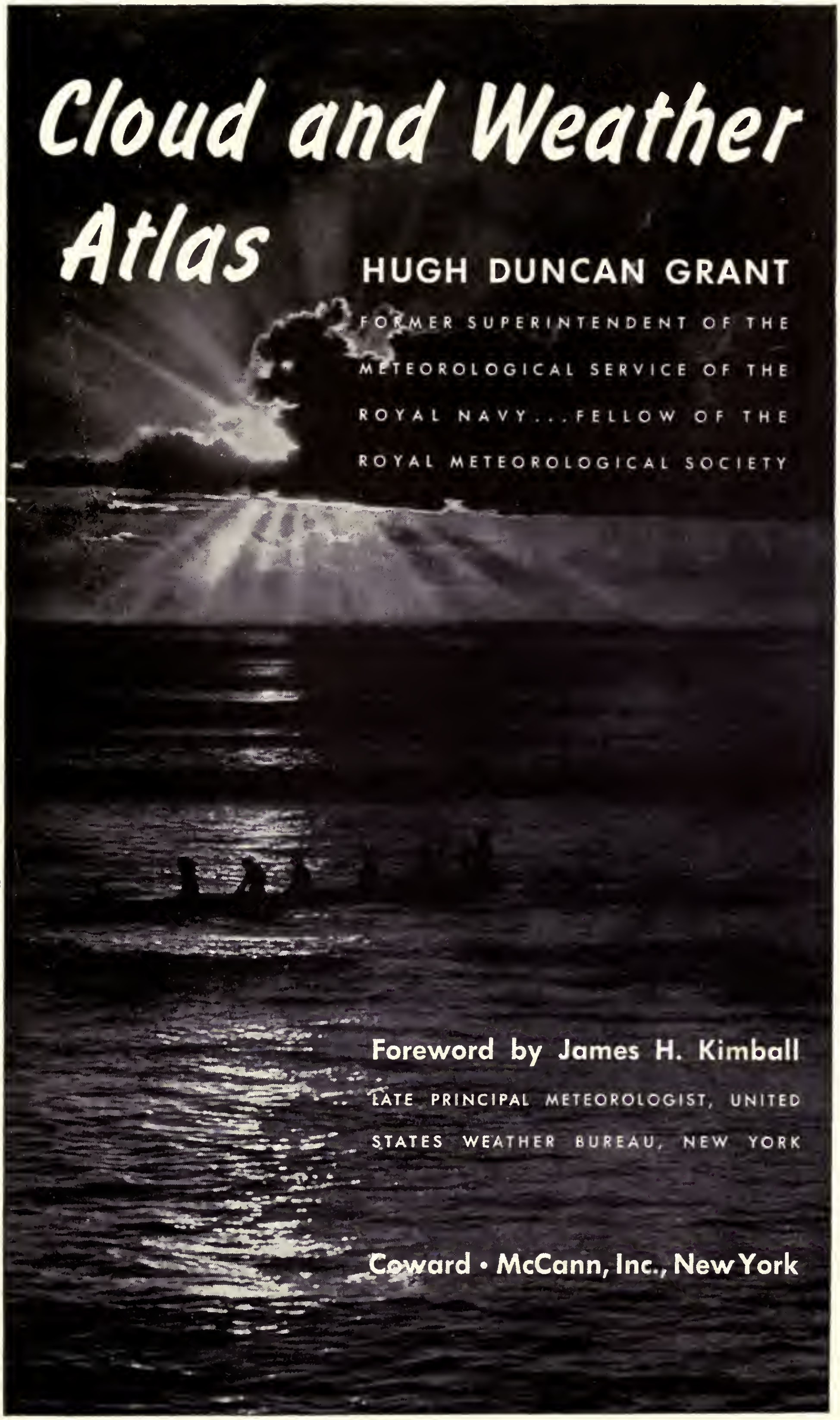
CLOUD AND WEATHER ATLAS



Cloud and Weather Atlas

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IMPORTANT

Government wartime restrictions on materials have made it essential that the amount of paper used in each book be reduced to a minimum. In this volume the number of words on each page has been substantially increased. The smaller bulk in no way indicates that the text has been shortened.

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FOREWORD

The meteorologist must ever be on the alert to observe the signs of the skies and ready to take advantage of the knowledge derived from his observations. Local observations, when assembled, provide a bird's-eye view of the weather existing at the time they were taken over the regions mapped on the synoptic weather chart. The state of weather at time of observation (present weather), weather during the interval between the current and the preceding observations (past weather), clouds, visibility, and, in the case of the mariner, state of sea and swell are all obtained by eye observation.

The result of condensation of water vapor above the surface of the ground into particles of water or ice so small that they remain suspended in the air—clouds—are indicators of coming weather changes. So often, therefore, does the rhyme apply that

> When clouds appear like hills and towers,
> The earth's refreshed by frequent showers.

Combined with the main characteristics of cyclones and anticyclones, the observer of nature—the agriculturist, the navigator, and the modern traveler, whether by land, sea, or air—should know not only the direction, velocity, changes in and frequency of winds at various altitudes; but also should he know the significance of transitions in cloud formation, the average height of the different categories of clouds, the size and general behaviorisms of thunderstorms, the phenomena connected with wind, heat, rain and electricity, the height, color, weight, and chemical components of the atmosphere, the optical appearances which objects present as seen through different atmospheric strata: in short, the many details of the air and its ways—the science which, since the days of Aristotle, has been designated METEOROLOGY.

While there are in existence many excellent treatises on general meteorology, this Atlas has been prepared with a view of aiding observers in the identification of the several cloud forms according to the International System of Classification. It is presented with the twofold purpose of stimulating interest in cloud study and of providing a compact volume of popular and practical interest.

James H. Kimball

To

Vice-Admiral Sir John Franklin Parry, K.C.B.

Vice-Admiral Sir Henry Percy Douglas, K.C.B., C.M.G.

Admiral of the Fleet Lord Keyes of Zeebrugge and Dover

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Over a period of years the late Dr. James H. Kimball, Principal Meteorologist of the New York Weather Bureau, and his successor, Benjamin Parry, have given me unstintingly of their specialized knowledge and experience. To the many people in the United States Weather Bureau in Washington who have courteously granted me time and attention in the midst of pressing duties I owe special thanks. Chief among these are Dr. William J. Humphreys, Ivan R. Tannehill, T. R. Brooks, R. C. Aldredge, and particularly Dr. Edgar W. Woolard who read and criticized the manuscript. In addition, Dr. K. B. McEachron, Director of the High-Voltage Engineering Laboratory, General Electric Company, supplied me with excellent photographs of lightning; and Peter E. Kraght, Senior Meteorologist, American Airlines, Inc., placed at my disposal his special knowledge of hazards in flight.

For facts or ideas which have been drawn upon in the preparation of the text I am deeply indebted to publications of the United States Weather Bureau and the Royal Meteorological Society. Most of the authors specifically mentioned in the footnotes have made such contributions. I must also mention Benjamin Parry, Senior Meteorologist, New York Weather Bureau, for his invaluable encouragement throughout the preparation of the book.

Although each photograph carries a credit line, I wish here to express my deep gratitude to the United States Weather Bureau, the Carnegie Institution of Washington, the United States Army Air Forces, the National Geographic Society, the General Electric Company of Schenectady, N. Y., the Soaring Society of America, the American Airlines, Inc., and the Pan American Airways for the use of photographs. Without their generosity this book would have been impossible.

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INTRODUCTION

All cloud forms have a story to tell, a story of increasing significance to the navigator by air, sea, and land. Anyone who looks closely at the skies, whether aviator, artist, or weather forecaster, cannot have failed to notice the variety of clouds on different days. He may not know that clouds are a direct expression of the physical processes taking place in the atmosphere or that, as indicated by actual measurements, there is a general relationship between the forms of clouds and their height. Clouds are, however, visible signs of definite schemes of motion followed by the air and reflect ever-changing conditions of temperature, moisture, and movements of the air at different levels above the surface of the earth. As a consequence, there are significant variations in the patterns assumed by clouds as well as the apparent effects of altitude or distance above the observer.

Inasmuch as clouds constitute the greatest, and certainly the most prevalent, obstacle to vertical visibility, a knowledge of their meanings is especially important to the aviator. If he can interpret correctly the shapes of clouds which run into one another by imperceptible gradations, he can avoid types dangerous to aircraft. From a study of them he can visualize the unseen air currents and learn much about flying conditions —wind velocity and direction, humidity, and temperature—at the cloud levels.

The purpose of this book is to translate into everyday language the all-important story of clouds—their part in analysis of the elements and in forecasting the continual changes in the drama of the weather. To that end the photographs are of prime importance, and in order to devote space to them, much interesting material has perforce been omitted and some of the discussions may seem more dogmatic than strict scientific accuracy would warrant. Wherever possible, in order to complete the discussion and facilitate further research, references have been made to more detailed studies.

In recent years meteorologists have been acquiring systematic observations over an increasingly wide area of the earth's surface and detailed data on the characteristics and circulation of the atmosphere higher and higher into the stratosphere. This recent advance in knowledge notwithstanding, it must be said of meteorology what Kipling said of aerial navigation: we are "at the opening verse of the opening page of the chapter of endless possibilities."

Cloud studies would be immeasurably enhanced by the operation of a world-wide network of weather-observing stations which would systematically transmit reports to a central office, and by a world-wide charting of weather in three dimensions. This is the task of the immediate future. To be understood and predicted, weather must be observed not only at a great many places without regard to political partitions of the earth's surface, but also by uniform methods. Perhaps early in the postwar world an international organization may be formed for systematic detailed study of humidity, velocity, and temperature conditions in the vicinity of clouds, inversions, and fronts. Already a totally distinct international organization of meteorologists devotes itself entirely to research problems—namely, the meteorological section of the International Geodetic and Geophysical Union. To forecast weather, the characteristics of weather conditions and their relationship to each other as a whole must be understood. Meteorology's success in serving mankind depends upon the close co-operation of meteorologists everywhere and the thorough co-ordination of their labors.

In this book clouds are classified according to form and appearance, but consideration is also given to the physical process producing them. Until some cloud forms have been reproduced in the laboratory, however, including types which remain a problem, there must be some doubt as to the interpretation placed upon them. In the main, definitions, descriptions, and code references are in conformity with the international classification adopted by most countries.

The following changes exist as between the system of cloud classification and practices heretofore in effect in the United States Weather Bureau and that recently introduced by the International Meteorological Organization.* The new deductions as defined are of much importance to the forecaster.

I. Cirrocumulus, a cirroform layer (1) must reveal some characteristics of ice-crystal clouds; (2) must evidence positive association with

* See *Codes for Cloud Forms and States of the Sky* (Circular S, W. B. No. 1249 U. S. Dept. of Agriculture, Weather Bureau).

cirrus or cirrostratus; and (3) must result clearly from a change in cirrus or cirrostratus. In brief, cirrocumulus must not be confused with small altocumulus patches on the edges of altocumulus sheets.

These restrictions therefore place real cirrocumulus in the category of an uncommon type of cloud. When ice crystals or spicules are observed floating in the air at the surface, the phenomenon, depending on visibility and other criteria for identifying hydrometeors, is recorded as ice fog or ice crystals.

II. Nimbostratus for Nimbus. Nimbus no longer exists, being replaced by the name "nimbostratus." A sharp distinction is drawn between nimbostratus and cumulonimbus, and the following characteristics are recognized as pertinent: (1) Nimbostratus is formed through the lowering of a sheet of altostratus or, in exceptional instances, from a sheet of stratocumulus, but not from cumulonimbus. (2) At no time and in no circumstances can nimbostratus apply to the lower portions of a cumulonimbus. (3) Precipitation falling from nimbostratus is continuous rather than intermittent.

III. Altocumulus opacus for dense Altostratus. Middle-level nonfibrous clouds appearing in dense sheets, hitherto called altostratus, are now classified as Altocumulus opacus. The outcome of this restriction is twofold, inasmuch as: (1) It limits the dense altostratus forms to the dense fibrous sheets of rain (sometimes snow) that generally succeed cirrostratus by the process of lowering. (2) It classifies as altocumulus rather than altostratus a dense sheet of middle-level cloud showing definite relief on its lower surface.

IV. Altocumulus is restricted and more definitely distinguished from Stratocumulus. This cloud generally forms a single layer of laminae, or rather flattened globular masses, and is fairly stable—that is to say, it changes but slowly. At the lower levels, where altocumulus may be derived from a spreading out of the tops of cumulus, it may easily be mistaken for stratocumulus. In calm weather in tropical and subtropical regions, the layer is frequently observable at the close of day at high altitudes. Fairly regular and of uniform thickness, the cloudlets or waves —always separated by clear spaces—comprising the cloud are neither large nor very dark.

However, should they be greater than 10 solar diameters in their smallest dimensions—i.e. the apparent width of 3 fingers when the arm is held extended—the regularly arranged and clearly defined elements observable in the layer are not altocumulus. Irisation on the thin and semitransparent edges of the elements is a sure mark of altocumulus as distinguished from cirrocumulus or stratocumulus.

V. Modification of the distinction between Cumulus and Cumulonimbus. Cumulus clouds of sufficiently great vertical development may undergo an extension of their summits while their bases may generally melt away. By the new definitions, no matter how heavy they may be and how great their vertical development, masses of cumulus clouds are not classed as cumulonimbus unless the whole or a part of their summits is transformed, or at least is in process of being transformed, into a cirrus mass. Cirrus composed of ice crystals—detached, delicate, and fibrous in appearance—are distinguished by the dazzling and silky whiteness of their edges, and are often arranged in bands which cross the sky like meridian lines. Owing to the effects of perspective, they are to be seen converging to a point, or perhaps to two opposite points, on the horizon. Cirrostratus and cirrocumulus often take part in the formation of these bands.

In the species Cumulonimbus calvus, however, no cirriform parts can be observed at first; but once the freezing of the upper parts starts, the tops begin to soften or lose their rounded outlines and clear-cut contours. Soon (in the upper portion of the cloud) the hard "cauliflower" swellings either disintegrate and dissolve, or they may show some horizontal spreading, leaving nothing to be seen in the white mass but more or less vertical fibers. Not infrequently there is a light shower below the central mass with a veil cloud at the left of the anvil summit. Hence, in cases difficult to identify the principal distinguishing feature is the fibrous (threadlike) summit that must be present if the cloud—characteristically a regular "factory of clouds"—is to be called cumulonimbus without having the clearly defined cirriform top. Frequently the central mass of vertical fibers is only one of several cumulonimbus clouds in the vicinity. Though only in relatively small quantities, precipitation may fall from cumulus clouds, especially those associated with thick cirrus and with extensions of stratocumulus and altocumulus. When cumulus show ice crystals at their summits, the inference is that they have reached the cumulonimbus stage, and they are so classified. In the first analysis, therefore, it happens that by extension at various levels, cumulonimbus may produce: (1) masses of altocumulus or stratocumulus, production of either being consequent upon the extension of the cumuliform parts which in turn may end by becoming detached from the parent clouds; or (2) cirrus masses, this species of upper cloud being brought about through an extension of its constituent ice-crystal parts. Halos are rare in cirrus.

In the International Atlas the term "state of the sky" has a double meaning. (1) In the code specifications the form and arrangement of the clouds in the sky at any given level—low, middle, or high—is held to apply to a "state of the sky" at that level. (2) The combination of all clouds in the sky—as for example, an "emissary sky," a "front zone sky," etc. In the latter sense it is used by the forecaster as an interpretation of the combination of code figures in the synoptic message.

The international meteorological classification gives 150 states of the weather. The term "precipitation" includes moisture reaching the surface of the earth in the form of rain, hail, snow, frost, dew, etc.

Scientific classification of cloud forms is comparatively recent, but elaborate attempts at naming them have been current. In the fourth century B. C., Indian statesmen are said to have known 80 kinds of rain clouds and 60 fine-weather forms. In the Western world, however, no such record exists before the opening of the nineteenth century, when the French scientist Lamarck proposed the following: "cloud sweepings," "clouds in bars," "dappled clouds," "grouped or piled clouds," "veil clouds," and "clouds in flocks."

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CHAPTER I

HOW CLOUDS ARE FORMED

What is it molds the life of man?
    The weather!
What makes some black and others tan?
    The weather!
What makes the Zulu live in trees,
And Congo natives dress in leaves,
While others go in furs and freeze?
    The weather!

Clouds are gigantic hieroglyphics spelling out the story of the weather on the open book of the sky. In the words of Ruskin, the sky is "sometimes gentle, sometimes awful, never the same for two moments together: almost human in its passions, almost spiritual in its tenderness, almost divine in its infinity."

These visible portents of weather to come, clouds, are formed by the condensation of water vapor at various elevations in the atmosphere. They are composed, not of vapor—which is always invisible; but of ice crystals or of exceedingly minute droplets of water, averaging about 0.001 inch in diameter. Change in temperature and pressure of the atmosphere brings about this condensation of the molecules of vapor into droplets, visible because they obstruct light.

THE SUN: The sun furnishes the power which makes weather and keeps it in motion. Rains fall, winds blow, and clouds form solely because the sun sheds upon our planet some two-billionths of its total radiation. An immense globe about 92,880,000 (mean) miles from the earth, the sun has a diameter of 866,000 miles and an average surface temperature of 10,000° F. Some 325 worlds like ours could be strung like beads around its equator. In order to accomplish its journey around the sun in 364¼ days, our sphere has to travel 1,580,765 miles a day, 65,865 miles an hour, or 18 miles a second.

Each square yard of the sun's surface constantly emits approximately 140,000 horsepower of energy. The minute portion of this energy which the earth receives in the course of a year is sufficient to melt a layer of ice 241 feet thick, covering the whole earth.

The amount of radiant energy in the form of ether waves received from the sun at any particular time and place, depends upon the nearness to the sun, directness of its rays, and duration of daylight. On January 1 the earth is nearly 3,000,000 miles nearer the sun than on July 1; hence more radiant energy is received in January than in July, the difference amounting to about 7 per cent. If the Southern Hemisphere did not have a preponderance of water area to stabilize its weather, it would have somewhat greater temperature extremes than the Northern Hemisphere because its summer comes when the sun is nearest, its winter when the sun is farthest away.

AIR TEMPERATURE: Fluctuation of the temperature of the air is largely governed by the amount of heat absorbed by and radiated from the surface of the earth. A layer of clouds serves to retain the heat near the surface.

We live at the bottom of an aerial ocean permeable in a unique degree by the solar rays and but little disturbed by their direct action. As the rays fall upon the earth, they heat it; as they fall upon the waters, they produce evaporation. The air in contact with the heated surface takes on part of its heat, expands, rises, and is replaced by colder air. Moreover, as the temperature increases, the air becomes less dense; as temperature decreases, it becomes more dense.

ATMOSPHERIC PRESSURE: The atmosphere is densest near sea level and grows progressively rarer at increasing altitudes. The density of the air depends upon atmospheric pressure; the greater the pressure, the denser the air, and vice versa. The pressure of the atmosphere is not constant, but increases or decreases from day to day and from hour to hour within a range normally of about 1½ inches. The speed of a storm's approach and its intensity are indicated by the rate and amount of fall of the barometer. The barometric pressure becomes less and less the higher we go.

Air at sea level is subject to the downward pressure of all the air above it; and air, though extremely light, has weight. This pressure is equal to the downward pressure of a column of mercury about 30 inches high, or a weight of about 14½ pounds to the square inch. The summit of a mountain a mile high has about one-sixth of the atmosphere below it; and there the downward pressure of the air supports a column of mercury only 25 inches high instead of 30.

WATER VAPOR: Water exists in the air in three states: (1) liquid—rain, water clouds, and fog; (2) solid—snow, hail, and ice-crystal clouds; (3) gaseous—invisible or gaseous water vapor, called "humidity." The elements so familiar to us—clouds, fog, rain, snow, hail, dew, and frost—all owe their existence to water vapor.

The heat of the sun puts water into the air by evaporation from the earth's surface—from the soil, the leaves of vegetation, and lakes and seas. It is estimated that 16,000,000 tons of water, on the average, are removed from the earth every second. The great bulk of the water taken up by the roots of plants escapes through the stomata into the air. For example, the average oak tree, in the course of its five months of growth each year, transpires or evaporates about 28,000 gallons of water—more than 180 gallons a day.

Although water vapor is a minute fraction of the total air, in many respects it is the most important constituent of the atmosphere. It is calculated to occupy 1,300 times as much room as the water drop to which it condenses. At the surface, the volume of water vapor varies greatly, from some 30 or more grams per cubic meter on a warm, moist summer day, to 1 gram or less on a cold winter day.

The higher the temperature of the air, the greater the amount of water vapor which can be mixed with it. At various times and places the moisture in the air varies from 2 to 3 per cent of the total weight of the air in which it is mixed, to a negligible amount, if any. Since warm air normally contains more moisture than cold air, the air is drier in Arctic regions than in tropical, and in winter than in summer, though the relative humidity may be very high. Water vapor is about five-eighths as dense as dry air at the same pressure and temperature; consequently, increase of the water-vapor content of the air decreases its density, and vice versa.

HUMIDITY, RELATIVE AND SPECIFIC: Humidity of the air means the amount of moisture suspended in it in vapor form. Specific humidity is the amount of water vapor present in a unit mass of air. Specific humidity of the air does not change with a change of temperature or volume, so long as the actual vapor content of the air does not change; whereas relative humidity is greatly affected by temperature.

Relative humidity is the degree of saturation of the atmosphere. This quantity is defined as "the ratio between the amount of moisture actually present in the air per cubic centimeter and the amount which would be present if the air were completely saturated." This is equivalent to the ratio between the pressure which the water vapor present in the air exerts and the pressure which it would exert if it were present in sufficient quantity to saturate the air. The temperature limits the amount of vapor which can be suspended in a given space, regardless of the presence or absence of other gases. If the temperature falls after the saturation point is reached, some of the vapor will condense in the form of dew or cloud.

DEW POINT: The dew point is the temperature to which the air must be lowered so that the moisture present shall be enough to saturate it, thus forming dew. In winter the dew point is usually below freezing. A conservative air-mass property, the dew point varies with the specific humidity.

When the dew point comes within 1° of the air temperature, fog usually gathers within a few hours. Conditionally—in such circumstances—if the wind increases or if the temperature is below freezing, a ground fog may form one hour after sunset, by midnight, by 3 to 4 a.m., or after sunrise.

CONDENSATION: The air surrounding the earth to a height of 200 miles or more consists of a mechanical mixture of gases, water vapor, and dust particles—the last being an essential factor in the formation of clouds and fog. Dust particles are the nuclei upon which water vapor condenses into droplets. If the drops are small enough to remain suspended in the air, and condensation takes place in the upper air, clouds are formed. The same process in the lower layers of the atmosphere causes fog to form. A visible vapor suspended at or near the surface—in effect a thin fog, the visibility of which is greater than 1 kilometer—is called mist. In the United States, however, the word "mist" is applied to a drizzle or rain of fine droplets.

In the general run of our weather, all clouds are the result of condensation of water vapor by the cooling of the air in some way below the dew point. At any given temperature, only a given amount of water vapor can exist per unit volume; and any further decrease in temperature will result in the immediate formation of clouds. If the cooling is sufficient to free considerable moisture, the drops become large and fall as rain, hail, sleet, or snowflakes.

The cooling of the air which produces condensation may be caused by colder air underrunning warm air, or by the production of convection currents—upward- or downward-moving currents of air mechanically or thermally induced.

CONVECTION CURRENTS: As the air nearest the surface of the earth is heated, a rising current of air will be formed, carrying with it the moisture due to evaporation from the ground. As the warm ascending air rises, it expands, and in the process loses some of its heat; the consequent cooling may force some of its moisture to condense, and a cloud will form at the top of the column. This will be a cumulus cloud, one of the large, billowy kind so often seen lazily floating across a summer sky. They are fair-weather clouds and bring rain only when they have reached an abnormal thickness.

The process described above is called thermal convection. Mechanical convection is the formation of rising air currents forced up by such mechanical means as mountains or other barriers. Air will ascend on the windward side of such a barrier and descend on its lee side.

TURBULENCE: Because the temperature of the air fluctuates, the time of day has a marked effect on wind velocity. As colder air takes the place of rising warm air, it brings with it the higher wind velocities of the upper atmosphere. The strongest vertical currents generally occur at levels between 10,000 and 20,000 feet. Turbulence, the irregular motion of the atmosphere better known to the pilot as "bumpiness," whether thermal or mechanical, applies to vertical air currents and horizontal as well. Gusts and lulls apply only to horizontal currents, or winds. The trail of smoke from a ship's funnel visualizes both turbulence and gusts and lulls.

Turbulence is produced when air flows over a comparatively uneven surface, or when two air currents flow past or over each other in different directions or at different speeds. It occurs largely at the boundary surfaces between vertical currents. An example is the scud roll, or roll cloud, close to the leading edge of a thunderstorm base. In effect, however, it is an eddy between a steady updraft and a downdraft immediately behind. As soon as the scud roll gives visual evidence of turbulence at the cloud base, similar current eddies may be anticipated between vertical currents within the cloud, and also in the clear air below it.

LAPSE RATE: When a particle of air rises, its temperature will decrease as the height increases. The rate at which the temperature will fall was formerly called "vertical temperature gradient," or "rate of temperature"; but meteorologists now prefer the term "lapse rate." The normal lapse rate, or simply lapse rate, is the actual temperature found in still air measured at different heights over a point on the earth's surface. This is usually 1° F. for each 300 feet, sometimes also given as 3.6°

F. per 1,000 feet. For example, if the temperature at the surface were 40° F. under normal conditions, at 3,000 feet it would be 30°.

The "dry adiabatic lapse rate" is the rate of temperature change assuming the air to be perfectly dry, and thus no condensation of moisture takes place during its ascent. This is 5.5° F. per 1,000 feet, or about 1° F. for each 188 feet. The "saturation adiabatic lapse rate," the temperature decrease of saturated air on rising, is always less than the dry adiabatic lapse rate.

TEMPERATURE INVERSION: When under special circumstances the temperature increases with height instead of decreasing, there is said to be an "inversion," meaning an inversion of the vertical gradient of temperature, or lapse rate.

ADIABATIC COOLING: The adiabatic process is a change in the temperature of a mass of air caused solely by a change in pressure. Increased pressure means increased temperature, and vice versa. In other words, adiabatic cooling (or warming) of the air takes place without the addition or removal of heat. As the pressure lessens when the air rises, the air expands. The energy required for expansion comes from the air itself in the form of heat, with consequent lowering of temperature.

FORMS OF CLOUDS

Clouds differ in their composition, height above the surface, appearance, and method of formation. Their forms are of great variety and beauty, from the elevated fog cloud, stratus—or "scud" to the sailor—and the luminous detached filaments which hover in the upper reaches of the atmosphere to the beautiful banner cloud floating like a white pennant from the leeward side of a mountain peak. Clouds form at all hours of the day or night, and are susceptible to classification. The numerous types of clouds and the many developments of each type are caused by the variation in lapse rates and seasonal variations in the heating of the earth's surface. In the late winter, for instance, as compared with the early part of the season, easterly winds are usually less cloudy because the air is drier to begin with and the surface of the air colder.

Hills and coasts, too, are likely to affect all clouds. For that and other reasons, more than one kind of vertical motion may be involved in any particular cloud.

Color and shade of a cloud depend upon the position of the cloud in relation to the sun and the observer. If you stand between a cloud and the sun, and the cloud is at a great distance, it will look white. But if it is overhead, you will see the lower surface which the sun does not reach, and it will seem to be black with a bright edge. Thus, when cumulus is opposite the sun, the surfaces usually seen by the observer are more brilliant than the edges of the protuberances. When the light comes from the side, cumulus shows a strong actual shadow; but on the sunny side of the sky it looks dark with bright edges. The true cumulus shows a sharp border above and below. Similarly, at the wind-torn edges of clouds, shafts of sunlight may gleam in falling rain.

In the light of dawn, at a ceiling of 20,000 feet, a thin cirrostratus overcast is often suffused with pinkish lavender. Fire-opal skies show clouds in ripples of flame. Snow clouds are usually extremely thick, and light sifted athwart their vast extent gives them a yellowish tint as the flakes descend.

In fine weather a traveler in hilly country, where the hills are cloud-capped as often as they are clear, may find himself observing the birth of clouds. As he climbs a slope ending in an abrupt cliff, with a cooler air blowing at his back, he may see smokelike exhalations drifting horizontally from the very lip of the cliff. These are the beginnings of those vast seas of vapor which in an hour can shroud the mountains from top to base, or, flowing and breaking, reveal the peaks in their most magical guise.

COMPOSITION OF CLOUDS: Clouds are composed of water drops or ice crystals—occasionally of snowflakes. Sometimes those made up of ice crystals look much thicker than water-drop clouds; their characteristic appearance is diffuse and nebulous, or fibrous. Since, however, many nebulous, ill-defined clouds are composed of water drops, it is sometimes difficult to tell whether a given cloud is composed of ice crystals or water drops.

Generally liquid particles, being smaller than ice crystals, fall more slowly—this despite the fact that the ice crystal's shape increases its head resistance. Small crystals are common over a large range of height. At the top of showers around a 5-kilometer level (about 16,500 feet), clouds are sometimes composed of rather large snowflakes.

Altostratus and nimbostratus may consist of water drops, small ice crystals, or snowflakes. Sharply defined cumulus, altocumulus, and probably most cirrocumulus, as well as lenticular clouds, consist of water droplets. Unless the clouds disperse, high cumulus tops eventually turn to ice crystals. Occasionally light snow falls below altostratus. When the water particles or droplets are too small to form crystals, coronas or iridescence may be the outcome.

CUMULUS: Dense, round-topped, fluffy, and with a flat base, cumulus clouds form when an upward current of air is created by convection in an atmosphere of high relative humidity, the entire process occurring high enough to cool the air to the dew point. The formation of the cumulus, or wool-pack, can be compared to the jets of steam from a locomotive exhaust. At every puff, so to speak, a cloud is formed.

The flat base of cumulus shows the height at which condensation must be supposed to start; the domed, turreted, or rounded tops indicate the presence of rising columns of air.

In cumulus there are all the predominant grades, from the small fleecy clouds of a fine summer day to the huge, towering storm clouds. If the lapse rate is rapid, carrying the rising air currents to much greater heights, cumulus will take on the massive proportions so common in spring and give rise to brisk and frequent April showers. If, on the contrary, the rate of temperature decrease is slight or moderate, the small cumulus of fine weather will be the outcome.

Often, in oppressively sultry weather in summer, just before a thunderstorm, strong ascending air currents laden with dust cause enormous banks of cumulus to form. As the clouds take shape, and more dust arrives from underneath, the normal white of cumulus proper may assume a dull yellow or red tinge. Such turreted cloud banks, reaching upward to heights of 5 miles, may look like mountain ranges afloat in the blue.

A remarkable wall of cumulus persisted along almost the whole of the southern coast of England throughout the afternoon of September 26, 1933. The air mass in which the cloud developed originated in the Bay of Biscay and overspread the English coast by way of northern France. Previously heavy rains and thunderstorms occurred in southern and central France. Since frcm its past history the air mass was so markedly damp to a considerable height, one of the essentials for thunderstorm development was present. During twilight lightning was visible in the upper part; after dark there was brilliant lightning from cloud to earth. An eyewitness, Mr. C. J. P. Cave, describes the formation as follows:

> The line extended as far as one could see in both directions.... It was a wall of cloud with many heads; top after top changed into hybrid cirrus, which melted away and was hidden after a time by new tops which grew up in front, and they in their turn changed into cirrus and were hidden by still newer tops; and so the process went on all afternoon. The wall of cloud

never seemed to get nearer, though I suppose in fact it did. By about 4:30 p.m. there was a rather rapid development of dark stratus in front of the cumulus, which hid a great deal of the clouds except the tops of the nearest clouds to the north. The stratus extended rapidly and extended southwards and finally turned into definite altocumulus. . . .*

A cumulus cloud, in whole or in part, is often slightly colder than its environment—the adjacent air at the same level; and also it very soon takes up the general velocity of that layer. In fine weather the air around the cloud is frequently dry. †

When cumulus clouds put in an appearance in the morning, they may differ little if any in temperature from the outside air. As a rule clouds which tower up rapidly are to some slight degree warmer than their immediate environment, whereas clouds of the flat fair-weather type are colder than the adjacent air. In general, large cumulus and cumulonimbus clouds are inherently buoyant. Large clouds with converging currents below, may be colder than their environments.

One cannot produce a thunderstorm with a forest fire unless the atmosphere is definitely unstable already; but a fire may create a cloud. In the Anglo-Egyptian Sudan it is customary for the natives to set fire to the grass after the rainy season. These fires cause local deterioration of visibility, and on occasions cumulus clouds develop above them. Photographs point to the presence of vapor directly above the peak of the fire, and lower down smoke. The air heated by the fire rises, there to condense its moisture and form a cloud. ‡

After the disastrous earthquake of September 1, 1923, fires broke out in Tokio and vicinity, lasting for forty hours. A strong gale and cumulus clouds over Tokio, said to be visible for twenty miles, were attributed to the action of the fire. The clouds were reported as sharp in outline, with fine, small spherical bulges, silvery white in color, or at least much whiter than ordinary cumulus. The top of the cloud was generally about 20,000 feet, but sometimes over 26,000 feet.§

* F. H. Dight, "Remarkable Cloud Formation on September 26th, 1933." In *Quarterly Journal of the Royal Meteorological Society*, 60, No. 256 (July 1934), 363-4.

† Fig. 6 in Vol. 18 of the *Journal of the Scottish Meteorological Society* shows a photograph, taken when a minor front was passing, of a large cumulus which was 2° C. colder than the surrounding air at 2.7 kilometers (8,858.16 feet).

‡ On page 279 of the *Quarterly Journal of the Royal Meteorological Society* for July 1940 is an interesting photograph and account of this phenomenon as reported by William D. Flower.

§ S. Fujiwhara, "Cloud Studies." In *Quarterly Journal of the Royal Meteorological Society*, 53, No. 221 (January 1927). See also photographs of the clouds mentioned as peculiar to Japan; meteorological observations taken during the Great Fire in Tokio; and a comparison of humidities at Tokio and Kamagai, September 1923.

CUMULONIMBUS: More impressive than cumulus in coloring and size is the thundercloud, cumulonimbus. When, mushroom-fashion, the large circular summits of cumulus commence to flatten out into rigid anvil-shaped forms, it is not unusual for a thunderstorm to follow. A familiar instance of a cumulonimbus thundercloud shows an anvil at 12,000 feet, towering up about a mile and a half from the bottom of the cloud. Extending from its anvil head, a rainbow may be seen touching the rain torrent at the surface of the earth. A mammatus structure, pendulous sacklike protuberances, appears either at the base of the cloud or on the lower surface of the lateral parts of the anvil. Sometimes a roll cloud, dark and shaped like an arch covering part of the sky of a lighter gray, and usually frayed out, accompanies the front of a thundercloud. Belonging properly to the role of fractostratus or fractocumulus, according to whether the cloud mass seems more cumuliform or stratiform, it is named Arcus.

The Japanese classify cumulonimbus developing from cumulus as a "heat" thunderstorm; the mixture of cirrus, altocumulus, stratocumulus, and cumulonimbus as a "front" thunderstorm. When the roll cumulus, sometimes seen in Japan, later develops into cumulonimbus, the cloud assumes a linear structure along the front, and at the same time a precipitous appearance on the front and back.

ALTOSTRATUS AND NIMBOSTRATUS: A thundercloud is easily identified in that it has many sharp, projecting points; it lacks the billowy look of the ordinary cumulus. The evolution of altostratus to nimbostratus may not, however, be so readily detected. The first step is for a layer of altostratus to wax thicker and lower until it assumes the characteristics of a layer of nimbostratus. Below the latter there is usually a progressive development of rather low ragged clouds, isolated at first, then condensing into an almost continuous layer. Nimbostratus can often be seen in the interstices of the underlying continuous layer.

As a general rule a cloud layer without fibrous structure, in which round cloud masses may be seen, is classed as altocumulus or nimbostratus rather than altostratus. The last may be encountered within fairly wide limits—6,000 to 15,000 feet—and is distinguished from a somewhat similar sheet of nimbostratus by the fact that it hides the sun and moon only in places behind its darker portions, but they reappear through its lighter parts. Nimbostratus, on the other hand, of a much darker and more uniform gray and nowhere showing any whitish gleam or fibrous structure, always hides the sun and moon in every part of it. Also, one cannot see the limit of its undersurface, which, owing to the rain which may not reach the ground, has a wet look.

STRATUS: There may be heavy or sharp showers from a cumulonimbus formation; but a fine drizzle or mist is usually the product, not of cumulonimbus, but of the stratus cloud. A veil of true stratus generally gives the sky a hazy appearance which must not, however, be confused with nimbostratus—that low, amorphous cloud layer of dark gray, not quite uniform and seeming to be illuminated from inside. In the Scottish Highlands, for example, a light form of precipitation covering the mountains and hilltops is none other than the proverbial Scottish mist.

In effect, stratus cloud, familiar to the mariner as "scud," consists of layers or sheets of fog uplifted some small distance above the surface of the earth.

WILL IT RAIN? The incidence of rain with both stratus and cumulus is not invariable. On some occasions they do not produce rain. At other times low stratus may develop merely into a fine drizzle or mist. In stratus the cooler, or denser, vapor is extended vertically in long masses, thin and spidery. The bottom of stratus represents perhaps one of the most common types of cloud mass at close range. As cirrus is the highest cloud form, so stratus is the lowest, its usual altitude being 500 to 1,000 feet above the earth. When this very low layer is broken into irregular shreds, it is called fractostratus.

Stratus and cumulus suggest in appearance a watery surface broken by gusts of wind. Sometimes, however, they lie in long wavy lines, indicating in the stratum of air in which they lie, a rolling motion of the atmosphere. A mackerel, or "rain tomorrow," sky is watery in appearance —the true rain type invariably followed by rain or snow.

CIRROCUMULUS, ALTOCUMULUS, CIRROSTRATUS: When, with or without halos around the sun or moon, a thin whitish sheet covers the sky completely, giving it a milky appearance, the cloud is cirrostratus. At other times, presenting a formation resembling a tangled web, it shows, more or less distinctly, a fibrous structure with disordered filaments. Even if there are no shadows, the presence of coronas or iridiscent colors near the sun or moon distinguish small altocumulus from cirrocumulus. Thin cirrostratus overcast, with a ceiling of 20,000 feet, is turned to pinkish lavender by the dawn. When, as the sun climbs, it shows a rainbow halo, the setting is a reliable omen of rain. Consequently, a milky veil of thin stratus is distinguished from a veil of cirrostratus of similar appearance by the halo which the sun or moon nearly always produces in a layer of cirrostratus. As a rule cirrocumulus represents a degraded state of cirrus and cirrostratus, both of which may change into it. In this event the changing patches often retain some fibrous structure in places. Real cirrocumulus is uncommon and should not be confused with small altocumulus patches on the edges of altocumulus sheets.

CIRRUS: Far above stratus, and in extreme contrast to the lurid hues of thunderclouds, a cloud of more ethereal appearance, cirrus, can be seen. Resembling a brush of extended plumes or long untrimmed "horse-tails" tossed by the wind, these clouds—distinguished particularly by the dazzling, silky whiteness of their edges—are usually composed of exceedingly delicate feathery crystals. Emissaries of the warm front, at and above 20,000 feet, they arrive first as feathery traces before gathering into an overcast. They usually consist of microscopic ice particles and are formed when convection currents reach these high altitudes before condensation takes place. Their transparency depends upon the degree of separation of the ice crystals.

When cirrus have extended so as to obscure the sky, rain is almost certain. The average velocity of cirrus is about 80 miles an hour, but in winter they have been known to travel at a rate of 230 miles an hour. In the highest canopies of "fish-scale" cirrus, each cloudlet is fringed with a faint suffusion like the shot iridescence of the nacre of a shell. These clouds are lighted up long before other clouds and disappear from view much later, turning gray after sunset. Halos are rather rare in cirrus.

When cirrus is arranged in radiating bands over part of the sky, like the meridians of a celestial globe, the fine fibrous cloud may be seen to converge in perspective toward one or two points on the horizon. On such occasions, owing to distance and the great thickness of air traversed by rays of light, they may seem to be arranged in parallel belts crossing a part of the sky in a great circle, and by an effect of perspective appear to converge on a point on the horizon—or, if sufficiently extended—toward the opposite point also.

Cirrus near the horizon at all hours of the day is often yellowish and in the most varied shapes, such as branching featherlike plumes, lines drawn across a blue sky, isolated tufts, curved lines ending in tufts, etc. Cirrostratus and cirrocumulus often form part of these bands.

BANNER CLOUD: The banner cloud is developed around a high mountain peak. It occurs in air so humid as to be on the verge of saturation, and the necessary cooling to produce the cloud comes from contact of the air with the cold sides of the mountain and, more largely, to a decrease in pressure in the region of eddies on the sheltered side of the mountain. Although it stays in one place, anchored to the peak, it keeps gaining new material and losing old; more moisture is continually drawn from below and added to the cloud.

CREST CLOUD: The crest cloud also comes into being in consequence of an exceptionally humid wind blowing up and over a mountain. As the resulting cloud hangs like a vast tablecloth over the mountain summit, it is fringed on the lee side. There it is being pulled and dragged down by the strong descending air current. To leeward the moisture evaporates.

LENTICULAR CLOUD: The term "lenticularis" is applied to clouds of an ovoid shape, with clear-cut edges and at times irisation. Lenticular clouds are smooth cloud patches and do not as a rule show many details of structure. In hill country smooth lenticular patches, maintaining a streamlined form, may be seen changing quickly to cumulus clouds. Lenticular clouds are sometimes called "foehn clouds" inasmuch as they are part of the gravitational flow of cold air downhill. They indicate certain regions of elevation in the eddy formed in a general current of air which passes over a mountain ridge.

WHERE CLOUDS DEVELOP: Keeping in mind the air-moisture-temperature balance, we find that clouds develop in seasons and amid conditions which are apparently remote but actually closely related. For example:

1. In the afternoon of a stifling summer day when the air is still, humid, and very warm to sultry.

2. On a day in winter that is cold and clear, or during the stillness of a winter night that is cold and crisp.

3. In the very early morning of a day in autumn when, perhaps, the leaves begin to fall listlessly from the trees.

4. In the Temperate Zones at almost any season when very low overcast skies of 600 to 700 feet or less prevail for many miles in all directions from the observer. Moreover, certain geographical features help in the formation of eddies and local clouds, affect the streamlines of the ground flow, and thus favor the prevalence of thunderstorms in an area so affected. For example, when very low clouds such as stratus predominate, or when temperature is high or relative humidity low, mountain ranges, functioning as barriers, may operate as centers of thunderstorms. The general flow so affected has an upward component on the windward side

and a downward component on the lee side. Not only do high mountains with freezing temperatures near the top retard a uniform distribution of temperature, but—in the general flow—they prevent the moisture-laden winds from crossing, thus producing aridity, or extreme dryness, on the lee side, combined with eddies dangerous to aviation. The locale becomes an area of increasing turbulence, sometimes reaching 200 miles or more to the lee. In effect, while the downward rush of air from the general flow dissipates clouds, the ascending current of air frequently does the opposite. If the air is unstable, the upward flow may produce general cloudiness and precipitation—convective clouds and showers—on the windward side. Intense mixing of the air follows as the eddies spiral to some considerable distance above the mountain range; and, given a favorable distribution of humidity and temperature, the mixing will lead to cloud formation above the mountaintops. Often stratus may be seen to form only on the mountainsides; or again a general layer of stratus may be lower on the mountainsides than in the free air.

Storm clouds from which we anticipate a thunder shower are formed by ascending currents of air over warm areas in summer. Made to rise by local heating of the sun, rain in great drops or sometimes hail may fall from their flat base, approximately the structural level of the cloud at which the air becomes cool enough for moisture to condense. Their ever-changing rounded top—a massive white pile resembling heaps of wool—is where the temperature has become equal to that of the surrounding air. The uprush of air referred to prevents smaller drops from falling. Most of our summer showers and thunderstorms come from clouds formed in this manner.

WHY CLOUDS DISAPPEAR AFTER SUNSET: Small, scattered clouds tend to disappear after sunset, as moonlight conspicuously reveals. The reason is that when the sun's rays are withdrawn, the clouds, radiating more heat than they absorb, rapidly grow colder and thus cool the adjacent air. This air thus becomes more dense than the surrounding clear atmosphere. The chilled air then sinks until equilibrium with the air about it is restored; and as it sinks it becomes heated by compression. When, finally, it reaches the level of equilibrium, it is warmer than it was before the clouds cooled it and started it on its downward plunge. Consequently, it has been warmed by cooling, with two results: the clouds evaporate and the air is made drier in terms of relative humidity than it was originally. The popular idea of the "moon eating the clouds" is therefore incorrect.

CLOUD SEQUENCE IN A "LOW": When a region of low pressure is approaching, cirrus are the first clouds to appear; but not infrequently a cumulus cloud will become greatly overgrown, and a cumulonimbus, or thundercloud, will be formed.

Always indicative of thunderstorms or heavy showers, cumulonimbus clouds—the final phase of cumulus—may be observed with their round tops spread out into anvil-shaped appendages. Being higher up, cirrus are less interfered with than the other cloud forms. Later, in our hemisphere, a wind is likely to blow from the southwest. Rain will then follow. Often, however, the cirrus clouds may never have formed, and local conditions may interfere with the winds. Unless the whole or a part of their tops is transformed or in process of transforming into a cirrus mass, masses of cumulus, no matter how heavy and how great their vertical development, must not be classified as cumulonimbus. When they cover nearly all the sky, the base alone is visible and resembles nimbostratus. Further, when precipitation takes place, it is violent and intermittent (showers) in the case of cumulonimbus as opposed to the relatively gentle and continuous precipitation (rain or snow) of altostratus.

TYPES OF SKY: There are four general types of sky:

1. Clear—the total of sky covered by clouds is less than 0.1 of the sky's area.
2. Scattered—0.1 to 0.5 enclosure is covered.
3. Broken—more than 0.5 but not more than 0.9 of the sky is covered.
4. Overcast—more than 0.9 of the sky is covered.

PRECIPITATION

Precipitation occurs when the condensed particles in the air become large enough to fall through the air. The form in which precipitation occurs depends upon temperature. When the vapor condenses as water and later freezes in vertical air currents, it falls as sleet; snow is formed only when saturation and condensation occur in temperatures below freezing. Dew and frost do not fall; they form directly on the surface of the objects on which they are found. After sunset the cooling of the air causes dew.

Rain and snow do not ride in on the wings of a storm; the drops and flakes are manufactured locally just about where they seem to drop from, and the output of a small cloud is sometimes prodigious. The quantity of precipitation which falls in any region depends greatly upon local causes, such as the variations of the surface, the prevailing winds, the proximity of the ocean, lakes and ponds, rivers, or other streams. Mountains and well-wooded islands usually receive more precipitation than any other kind of surface. Other sources which supply water vapor are wet soil, falling rain or snow, and plants during their growing or mature states.

Precipitation falls from veil clouds and from cumulonimbus by night and by day, the transformation from cloud elements to snow or raindrops being often very rapid. In Khartoum the monsoon cloud gives rain only at night.

Dark, heavy clouds may remain almost stationary or move across the sky without releasing any rain; then suddenly light streamers of rain appear, and soon rain begins to fall under the entire cloud mass. A heavy haze may prevail at any particular level in the air before the formation of a cloud.

RAIN: Rain falls from clouds only when cloud droplets cling together to form a raindrop heavy enough to fall. Raindrops vary in size from a fifteenth of an inch in diameter for a light rain, to an eighth of an inch or more in a cloudburst or heavy downpour. In the latter event, larger water drops form on the nuclei because each dust mote, or nucleus, receives a very heavy coating of water. These large drops fall comparatively fast, overtaking and swallowing up smaller drops along the path of descent.

Very hard rains have been defined as "those which yield 2 inches of water within 30 minutes, 3 inches in an hour, 4 inches in 8 hours, 5 inches in 16 hours, 6 inches or more in 24 hours. 'Numerous' means five or more such rains per year, 'rare' means only one rain of any of these five magnitudes during an average decade or longer." *

When a cloud floats very high above warm air, the vapor of which is unsaturated, the falling drops of water will evaporate before reaching the earth. If, however, the cloud is low, or the water vapor in the air through which the drops pass is saturated, or almost so, evaporation is so slight that the raindrops will reach the ground unaffected, or possibly larger than before.

A heavy fall of rain comes when considerable vapor is rapidly con-

* S. S. Visher, "Precipitation Regions in the United States. In *Quarterly Journal of the Royal Meteorological Society,* 69, No. 302 (October 1943), 272.

densed close to the surface, or above air which is completely full of water vapor. Dry air, on the other hand, is characterized, as a rule, by clear skies even in areas usually partially clouded. In the United States the dryness in summer of the Pacific Coast is largely due to the land's being much warmer in summer, with the result that winds from sea to land are heated by the land sufficiently to retain their moisture.

SNOW: Snowflakes are crystallized water and are built on patterns resembling beautiful six-rayed stars. The size of the flake and its pattern depend upon the temperature at which the flake is formed.

The true color of snow is bluish or greenish, like a cake of ice. Reflection and refraction of light over and over again among the many small crystals is what produces the effect of whiteness. A large amount of air is entangled between the spicules of snowflakes.

Snow falls when the air is cold enough so that the moisture condenses in the ice stage instead of as water. A shower of snow may be made to fall from a ceiling by suddenly condensing the warm air with a current of cold air admitted through an open window. This experiment may be performed successfully in a small hut which has not been ventilated for several days. When vapor nearly saturates the atmosphere and is then acted on by a current of air below 32° F., snow will result. Provided the prevailing temperature is below freezing, such condensation may occur at any elevation. Snow does not, therefore, necessarily come from clouds, which explains why mountains towering above cloud level nevertheless are capped with snow.

Snow consisting of small, nontransparent grains is described as "granular snow."

SLEET: Official definitions of sleet are as follows: (1) The United States Weather Bureau describes it as "frozen or partly frozen rain; frozen raindrops in the form of particles of clear ice." (2) The International Meteorological Organization and the British Meteorological Office use the definition, "snow and rain falling together." In popular and technical usage in the United States, the term "sleet" is often applied to a coating of glaze on trees, wires, rails, and so forth.

GLAZE: According to the United States Weather Bureau, glaze is "a smooth coating of ice on terrestrial objects due to the freezing of rain; often popularly called sleet." The British Meteorological Office describes such a deposit as "glazed frost."

A deposit of glaze on a large scale constitutes an ice storm. On aircraft, heavy coatings of ice consist of a mixture of rime and clear ice.

HAIL: A thunderstorm phenomenon, hail consists of balls or irregular lumps of ice, complex in structure and often quite large. Very few thunderstorms, however, contain hail; it is estimated that about 1 out of 400 brings hailstones. Flying in a thunderstorm above 4,000 feet and below 12,000 feet, violent air currents, and perhaps hail, may be expected.

Large hailstones usually have a core surrounded by layers of ice which may be alternately clear and cloudy. "Soft hail" consists of round, opaque white pellets of snow.

DEW AND FROST

DEW: Dew is atmospheric moisture condensed in liquid form upon objects cooler than the air. Because warm air can hold in suspension a larger quantity of moisture than cold air, the cooling of the air with the fall of night makes some of the moisture condense in the form of dew. If the temperature is below freezing, however, frost is formed instead of dew.

Dew forms more rapidly when the air is calm than when it is in motion, because when the air is moving, there is more of it to be saturated. Dew forms more abundantly on clear, cloudless nights because a cloudless sky does not return much of the heat radiated from the earth, hence cloudless nights are cooler. Dew forms on vegetation in preference to the bare ground because vegetation radiates heat readily and cools off rapidly, as well as giving off water vapor.

FROST: Frost is not frozen dew; it is moisture congealed directly into the ice stage on terrestrial objects. It is composed of small separate ice crystals, and is sometimes called "hoar frost."

RIME: The term "rime" is applied to hoar frost, an opaque whitish ice with a granular texture; or to a feathery coating of ice deposited upon terrestrial objects by fog. This latter definition is the one now used in technical literature.

ICE: Ice is the solid form of water. It contracts, like most solids, upon being cooled. Freezing is facilitated by the stillness of the water, resulting from the absence of convection currents below 4° C. Characteristically, sea water does not freeze until it is cooled to about —2° C., and the ice produced is free from salt. Ice at 0° C. has a density only 0.9175 that of water at the same temperature, and therefore floats on cold water.

Thin crystals or shafts of ice, so light they seem to be suspended in the air, are called "ice needles."

An iceberg, a floating mass of ice broken from the tongue or end of a glacier or a polar ice sheet, shows only one-ninth of its mass above water.

"Ice rain" is either a rain that causes a deposit of glaze, or falling pellets of clear ice, called sleet by the United States Weather Bureau.

Official Photograph, U. S. Army Air Forces

WHEN CLOUDS OBSCURE THE SUN. The lower clouds are of great value as heat curtains, preventing the rays of the sun from being too hot by day and almost entirely checking the loss of heat by radiation from the earth at night.

The photograph above shows a typical horizontal deck of altocumulus. The turreted tops of vast cumulus protrude through the cloud sheet, and there is some cirrostratus overhead. This cloud formation should not be confused with low stratus and stratocumulus; its top range is the middle troposphere—a height of 2 to 4 miles. In polar zones stratus is the commonest cloud, sometimes blanketing the sky for days without a break. Toward the inner polar areas, cloudiness decreases after passing the belt of high cloudiness in the higher latitudes of the Temperate Zones.

Photo by Hans Groenhoff

THE ALL-SEEING EYE. From a distance of 93,000,000 miles the sun preserves a watchful eye over the earth. Here it shines through the center of a cloud in the shape of a boar's head. Shakespeare expressed the common tendency to see resemblances to animals in cloud forms:

"A cloud that's dragonish;
A vapor sometimes like a bear or lion."

Directly or indirectly, the sun provides all the energy for the pageant of weather. The ceaseless motion of the winds, the evaporation of water into the air, only to be carried over the earth and returned by the rains—the whole process is due to the energy radiated from the sun. Water, snow, and clouds are the best reflectors of solar radiation.

Courtesy, U. S. Weather Bureau

CREPUSCULAR RAYS. Sunbeams and crepuscular rays are seen in the late afternoon and sometimes in the early morning. The sun's rays shine through interstices in the clouds, their path made luminous by dust suspended in the air. In the upper part of the photograph is stratocumulus formed by degeneration of a mass of cumulus. Fragments of cumulus bulges are visible to the right.

The photograph on the title page also shows crepuscular rays.

On rare occasions, at sunset or shortly afterward, the sun shines through broken clouds, and anticrepuscular rays are seen across the sky. As shown in the photograph on the following page, these rays converge at the antisolar point. They are thus the continuation of crepuscular rays. (For fuller discussion, see John G. Albright's article in "Monthly Weather Review," 63 [1937], 3.)

Photo by J. G. Albright; Courtesy U. S. Weather Bureau

ANTICREPUSCULAR RAYS. By an effect of perspective, the rays converge at a point in the sky opposite the sun. See under "Crepuscular Rays" on the preceding page.

Courtesy, U. S. Weather Bureau

SUN BREAKING THROUGH STRATOCUMULUS. The stratocumulus here is a layer showing great rolls of dark patches in parallel lines, with the sun breaking through.

Courtesy, Hamburg-American Line

TROPICAL OVERCAST. This picture, taken from the Graf Zeppelin on a coast-to-coast flight across the South Atlantic, shows a stratum of clouds overhead, behind which the sun is momentarily screened. Near the Equator, and in the tropics generally, days wholly clear are very rare. In Peru and off the western shores of Africa—the latitude of flight—ocean fogs are a common occurrence. Dull days with overcast skies, corresponding to winter in the Temperate Zone, are frequent along tropical coasts in the neighborhood of cold ocean currents.

In the streak of bright sky between water and clouds in the picture, the sunlight is vividly reflected on the water, showing the edge of the low mass of cloud. There are also vestiges of an altostratus sheet illuminated by the sun. In the pageant of tropospheric weather, clouds and precipitation in tropical or semitropical areas duplicate in magnified form the summer conditions of much of the North Temperate Zone.

CHAPTER II

CLOUD REGIONS AND BEYOND

Our globe is encircled to a height of a few hundred miles by a gaseous film which adheres to its entire spherical surface. This ocean of air in which we live is composed of about 20 per cent life-giving oxygen, 80 per cent nitrogen, minute proportions of several rare gases, and a variable amount of water vapor, ranging from a trace up to about 4 per cent by volume or 2.5 per cent by weight.

Consisting of a mechanical mixture and not a chemical compound of gases, the atmosphere becomes less dense with altitude. Its total weight is approximately 58 quadrillion tons, or the equivalent of a layer of water 34 feet deep. At sea level the weight, or pressure downward, of the atmosphere is equal to 1.05 tons per square foot, or 14.7 lb. per square inch. Thirteen cubic feet of air weigh 1 lb. at sea level at 32° F.; and 1 cubic foot weighs about 1.25 ounces. The earth itself is 5.6 times as heavy as a sphere of water the same size.

At 17,000 feet the atmospheric pressure is 7.35 lb. per square inch. Indeed, so rapidly does the density of the air decrease as we ascend in it, that at an altitude of about 3.6 miles the air is only half as dense as at sea level. If it had the same density throughout as at the earth's surface, it would have a height of about 5 miles—sometimes called a "homogeneous atmosphere." At 34,000 feet (6.43 miles) the atmospheric pressure is 3.675 lb. per square inch.

EARTH'S AIR SHELLS: This gaseous envelope, a conductive medium through which the sun's rays penetrate at a speed of some 186,000 miles per second, consists of at least five almost concentric shells having separate and distinct regions, as follows:

1. TROPOSPHERE — 0 to 9 miles up

   All ordinary clouds are confined to this shell. Temperature changes from warm to bitter cold at a rate of approximately 17° per mile.

2. TROPOPAUSE — 5 to 9 miles up

   This layer is still colder, although the rate of change is not quite so rapid.

3. STRATOSPHERE 9 to 30 miles up

This region is just slightly colder, but as we go higher it maintains about the same temperature.

4. OZONOSPHERE 30 to 50 miles up

As it absorbs much of the ultraviolet rays coming from the sun, this layer becomes warmer.

5. IONOSPHERE above 50 miles

Long waves travel by bouncing between the surface of the earth and this region. Not only so, but as they travel into space radio waves transfer a good portion of their energy into another form by setting up motions of the electrified particles in the *ionosphere*. In turn, these particles set up radio waves of the same pattern as those which put them into motion. In the course of such movement the electrified particles may collide with neutral particles, such as those of oxygen and nitrogen, and deflect or arrest this motion. As a result, radio energy is either scattered or lost—absorbed, in other words.

Owing to their extreme height and the little known of them, the ozonosphere and ionosphere do not enter into a discussion of clouds.

THE TROPOSPHERE: The region of clouds, extending a few miles above the earth, exists only in the troposphere, the dust-laden region of rising and descending air currents, of clouds, storms, and variable temperature. This layer adjoining the earth contains three-fourths of the total atmosphere and extends to a height of some 5 miles above the poles, 7½ miles above the Temperate Zones, and 9 to 10 miles above the Equator. All clouds except the high, thin dust clouds are confined to the troposphere.

THE TROPOPAUSE: Separating the troposphere from the stratosphere, the surface known as the tropopause is the boundary between the known and the uncertain. At this point the regular fall of temperature with height ceases. Over the average of the earth the height of the tropopause, which marks the base of the stratosphere, varies between 5 and 9 miles above sea level, depending upon the latitude and season. It is higher over anticyclonic than over cyclonic areas, and higher in good weather than in bad. At the poles the fluctuation with seasons is slight; at the Equator scarcely any.

THE STRATOSPHERE: In this upper or isothermal layer of the atmosphere, the temperature remains curiously constant at about $-75°$ F., and only horizontal air currents are found there. Consequently it is free from active convection. Easterly or westerly gales blow through it, steadier and stronger than those normally occurring in the troposphere. Since there are considerable variations in its height above the earth, the base of the stratosphere may be considered as roughly a spherical shell. It contains only one-fourth of the total gases of the atmosphere. Contrary to popular supposition that the earth's upper atmosphere consists mainly of the lighter gases such as helium and hydrogen, spectral photographs reveal the presence of nitrogen and oxygen extending to the extreme limits of the atmosphere. On rare occasions volcanic eruptions have shot dust high into the stratosphere.

REFLECTION AND REFRACTION OF LIGHT: The invisible heat rays and the visible light rays from the sun fall upon a variety of things on their way to the earth—such things as pure air, dusty air, clouds, water, and so on. Arranged in order of their power to reflect light, these are: water, snow, clouds, dusty air, earth, and pure air. The last, pure air, reflects practically nothing; snow and water reflect from 30 to 50 per cent. Air does, however, scatter light strongly in all directions.*

UPPER-AIR SOUNDINGS: Instruments automatically recording temperature, humidity, and pressure, carried aloft in kites, balloons, or airplanes, have clarified much of the mystery of the lower air and of the lower levels of the stratosphere. But no unmanned balloon scouting for meteorological data has yet risen higher than 22 miles.

There are two general classes of meteorological studies—surface and upper-air. Some surface observations, consisting of the state of the weather, visibility, and type and amount of clouds, are made by visual methods of observation as distinguished from instrumental. The remaining meteorological elements—temperature, pressure, precipitation, ceiling, wind velocity (and direction), and humidity (dew point)—fall in the category of instrumental observations.

Upper-air soundings are made to determine pressure, temperature, and relative humidity in the upper levels of the atmosphere, for the following reasons: (1) to determine the stability of the air for thunderstorm or shower forecasting; (2) to determine the ice level at individual sta-

* See further E. W. Hewson, "The Reflection, Absorption, and Transmission of Solar Radiation by Fog and Cloud." In *Quarterly Journal of the Royal Meteorological Society*, 69, No. 301 (July 1943), 227.

tions; (3) to locate frontal surfaces above the ground station; (4) to determine temperatures at all elevations; and (5) to ascertain at what levels clouds will form and of what types they will be. Upper-air soundings are made daily by pilot balloons, radiosondes, and automatic weather robots at points scattered all over the world. Prior to the war, in 1940, the United States Weather Bureau alone had some 138 well-distributed stations equipped for taking upper-air wind observations by pilot balloon, and additional stations at which upper-air observations were made by radiosonde. From these reports vertical weather maps, which have done much to assist accurate forecasting through the air-mass-analysis method, are prepared. Not infrequently, however, fog and cloud preclude the taking of soundings to very high levels.

Pilot balloons without radio attachments sound the upper air to ascertain the direction and speed of the wind to considerable heights. At times the balloon is followed by means of the theodolite to heights of over 50,000 feet, and in rare instances to 100,000 feet.

Radiosondes are sent aloft attached to small balloons which break at certain altitudes, releasing parachutes which carry the radiosondes safely to earth. A notice attached informs the passer-by who picks one up that he will receive a reward for mailing it to the United States Weather Bureau. The radiosonde is a small carton wrapped in tinfoil, actually a radio transmitter coupled to a thermometer and a moisture meter. The balloon to which it is attached may take an hour to reach the stratosphere, and all that time the radiosonde signals its readings in a metallic voice, which suddenly stops when the balloon bursts. The radiosonde may rank in importance with the invention of the barometer by Torricelli.

The automatic weather robot, a cousin of the radiosonde, broadcasts the atmospheric pressure, temperature, and relative humidity. It may be anchored in the sea or planted in uninhabited regions where it would be difficult to place human observers. It has many uses of increasing importance. Light in weight, it contains instruments for registering temperature, humidity, and pressure; a timing device driven by clockwork; arrangements for translating the instrument readings into electrical signals; and a small radio transmitter. An automatic weather robot may be serviced only once in several months.

THE CEILING: The ceiling may graduate from a zero altitude at the earth's surface to the distance from the base of clouds to the ground when the sky is overcast with clouds below 10,000 feet. It is thus affected by the degree of cloudiness, or whether the sky is wholly or partially covered with clouds; or whether heavy precipitation, dense fog, or other conditions are present, preventing the observer from seeing any cloudiness. If it is only partly cloudy, but sufficient to obliterate from the observer one-half of the blue sky, the base of the lowest cloud would be regarded as a ceiling.

LIMITATIONS OF FLIGHT: In the stratosphere, in order to fly safely, an airplane must be sealed and its air supply conditioned against subfreezing temperatures and thin atmosphere. Inside the plane, means must also be available to equalize such stresses and strains as may be caused by rapid changes in temperature and by hermetically sealing those parts of the aircraft containing passengers or crew. Above 25,000 feet the air is so thin that it is impossible to whistle.

In the troposphere, observations show air moves in many ascending and descending currents, causing the formation and dissipation of clouds. Air movements in the stratosphere—"this most excellent canopy, the air, . . . this brave o'erhanging firmament, this majestical roof fretted with golden fire"—are responsible for our weather; and, as the movements in the lower levels are affected by those at upper levels, definite information concerning what is happening at those heights is of value not only in weather forecasting, but also for the stratospherist as a would-be commercial flier of the future.

THE BALLAD OF THE STRATOSPHERE*

I am the rolling Stratosphere,
  I long to perturbate;
So I tickle the top of the troposphere
  To make him undulate.

My temperature is 215 (two-fifteen),
  On Kelvin's absolute scale,
Though it's never been taken in a louvred screen,
  It has in a comet's tail.

I rule the air beneath my feet,
  I'm in a stable state,
When the sun is shining through a cirrus sheet
  My base I elevate.

* *Symonds Meteorological Magazine,* December 1914. By permission of the author, Colonel Ernest Gold, D.S.O., F.R.S.

I was discovered, most men agree,
By Teisserenc de Bort;
From Trappes his balloons he sent floating free
Through my "Great Inversion" floor.

In England Dines has found me out
With instrument so light;
And my secrets he's sought with courage devout,
And correlation might.

But no correlation ratio,
For kilometres nine,
Can explain to me why a small shallow low
Brings rain from the land of wine.

Where Simpson made a dash for me
Antarctic East wind blows;
So he tried calm days when (See Admiral B.),
Smoke vertically rose.

I am the rolling Stratosphere,
I keep, need I relate,
By the radiation of the Atmosphere
In a thermal steady state.

Official Photograph, U. S. Army Air Forces

RELEASING A RADIOSONDE. Radiosonde is a miniature radio transmitter attached to a pilot balloon, which bears aloft instruments to transmit automatically reports on weather conditions at high altitudes. Through the information thus gained, weather maps not merely show highs and lows, but locate the air masses and warm and cold fronts.

Official Photograph, U. S. Army Air Forces

PREMETEOROLOGY TRAINING. The photograph shows a cadet at Premeteorology for Army and Navy Studies, University of California.

Official Photograph, U. S. Army Air Forces

PILOT BALLOON. Releasing a balloon to determine wind direction and speed aloft.

CHAPTER III

CLOUD CLASSIFICATION

Upon what basis are clouds classified? Primarily upon the approximate relationship between the shapes of clouds and their height. This procedure was demonstrated in 1896 by observers at meteorological stations all over the world, in what is known as the International Cloud Year, the object being to learn something about the wind system of the globe. Since it brings cloud observations throughout the world to a standard level of equal comparison, the importance of an international classification of clouds as now accepted cannot be overestimated. Thus, for example, an airplane pilot is enabled accurately to interpret the significance of clouds; whereupon he can either avoid the types which are dangerous to aircraft or take prescribed precautions in the given circumstances.

Recognizing 10 types of clouds, the International Cloud Classification has been in general use since the close of the last century. In 1930, however, a few important alterations were introduced to the International System of Classification of 1905, essentially changes relating to detail. The 10 major cloud types are still recognized. Meteorologists of many countries gathered in international committees have modified the original classification. For the use of observers, the "International Atlas of Clouds and the State of the Sky," issued in 1930 by the International Commission for the Study of Clouds, gives the new classification in detail. In agreement with the International System of Classification of 1930, and subsequent revisions, clouds may be divided into three main categories: *

1. Isolated heap clouds
2. Sheet clouds
3. More or less continuous cloud sheets

The characteristics of each category may be noted as follows:

* In 1803 Luke Howard, a British pharmacist and naturalist, published his classification of clouds consisting of but three primary forms to which he applied a descriptive Latin name—*cirrus, cumulus,* and *stratus;* three components of these forms; and the *nimbus,* or black rain cloud (*cumulo-cirro-stratus*). A revised edition of Howard's *Essay on Clouds* appeared in 1865.

1. Isolated heap clouds develop vertically and spread out when dissolving.

2. Sheet clouds may be stable or in process of disintegrating. They may consist of filaments, scales, or rounded masses.

3. More or less continuous cloud sheets lack stability, being more often than otherwise in process of formation or growth. In thundery conditions degenerate cloud forms are more the rule than the exception.

TYPES OF CLOUDS

There are ten types of cloud, arranged according to their height above the ground, as follows:

Family A—High Clouds

Level—Mean lower level, 20,000 feet, 6,000 meters *

1. Cirrus (Ci)—the feathery ice cloud
2. Cirrostratus (Cs)—Curtains of the coming night
3. Cirrocumulus (Cc)—Mackerel sky

Family B—Middle Clouds

Level—Mean upper level 20,000 feet, 6,000 meters; mean lower level 6,500 feet, 2,000 meters

4. Altocumulus (Ac)—The Herringbone
5. Altostratus (As)—Whirling altostratus

Family C—Low Clouds

Level—Mean upper level 6,500 feet, 2,000 meters; mean lower level, close to the surface

6. Stratocumulus (Sc)—Not necessarily associated with rain
7. Stratus (St)—Lifted fog in a horizontal stratum
8. Nimbostratus (Ns)

Family D—Clouds with Vertical Development

Level—Mean upper level, that of cirrus; mean lower level, 1,600 feet, 500 meters

9. Cumulus (Cu)—The wool-pack or cloud with the silver lining
10. Cumulonimbus (Cb)—The thundercloud, shower cloud

In the International System there are, thus, 4 families and 10 genera, with in addition certain species, varieties, and special features.

* Subject to allowance for marked variation, normal classification according to form and appearance is also, in effect, classification according to height. For example, whereas in polar regions cirrus may reach almost as low as the surface, in temperate latitudes it is rarely if ever found below 10,000 feet (3,000 meters). Mean heights given, therefore, apply to temperate latitudes and to the general level of land in the region instead of to sea level.

Though the number of forms that clouds may take is almost unlimited, the number of types of clouds is rather limited. Inasmuch as special shapes or characteristics are peculiar to most if not all of the above 10 types, they are in most cases given names.

Wind-Blown Clouds: The prefix "fracto" ("broken") applies to wind-blown clouds, as:

Fractostratus (Fs)
Fractonimbus (Fn)—"Scud of the Sailors"
Fractocumulus (Fc)

Detached or Isolated Cloud Forms of Unusual Origin and/or Peculiar Form:

Cumulonimbus mammatus (mammato cumulus) (Cm)
Altocumulus castellatus (Acc) or scattered cumuliform tufts
Lenticular Cloud—existing at all levels, from cirrostratus to stratus
Banner Cloud

Cloud forms are frequently the expression of definite schemes of motion followed by the air in regions below as well as above them. A study of the physics of clouds falls into two headings: (1) ice crystals and water drops; and (2) the nature of the physical and dynamical processes leading to condensation.

The study of crystals and water drops means a study of the cloud particles, inasmuch as they have an important bearing on cloud structure. Coronas or iridescence indicate droplets, or at least water particles too small to form crystals.

The nature of the physical and dynamical processes leading to condensation is a problem which in the main resolves itself into a study of the various types of vertical motion in the atmosphere. Nevertheless, in the case of any particular cloud, more than one type of vertical motion may be involved.

APPROXIMATE CLOUD DIVISIONS IN TERMS OF ORIGINS *

1. Cloud systems due to the slow upward motion over a large area, usually associated with continuous precipitation.

   Nimbostratus
   Altostratus
   Cirrostratus
   Some forms of cirrus

* As proposed by C. K. M. Douglas in "The Physical Processes of Cloud Formation," in *Quarterly Journal of the Royal Meteorological Society,* 60, No. 256 (July 1934),

2. Clouds due to smaller air masses rising through their environment.
   - Cumulus
   - Cumulonimbus group—including cirrus or broken alto-stratus formed from anvils

3. Clouds due to turbulent motion. These may be irregular or arranged in distinct layers.
   - A. Irregular
     - Fractonimbus
     - Fractostratus
   - B. Arranged in distinct layers
     - Stratus
     - Stratocumulus
     - Altocumulus
     - Cirrocumulus

4. Lenticular clouds and cloud patches of smooth appearance indicating local ascent of a damp stratified layer.

From a physical point of view, cirrus in its many forms is extremely difficult to classify in this manner. Moreover, since the processes of nature are complex and infinitely variable, clouds in general are not capable of being too rigidly divided into categories.

CLOUD ABBREVIATIONS *

Abbreviations in the International Atlas are of the form shown by the following examples: Cist., Acu., Stcu., and Cunb., etc. These merely constituted a simplification of the abbreviations previously used, for example, Ci-St., A.-Cu., St.-Cu., and Cu.-Nb., etc. The International Meteorological Organization in a meeting in Warsaw in 1935 adopted shorter abbreviations

333-41. On the subject of the physical processes involved in the formation of clouds, J. Bjerknes and Douglas were signatories in 1926 to a joint memorandum to the International Commission for the Study of Clouds. It is hoped that the postwar era will develop the desire therein expressed—and that of most meteorologists—for an intensive study of this vital subject. The reader is also referred to a scholarly treatment by Douglas, "Altocumulus Castellatus Clouds and Thunderstorms," in the *Meteorological Magazine,* 66 (1931), 106; and to an outlined discussion at the Meteorological Office, London, on the physics of cloud precipitation, reported in the *Quarterly Journal of the Royal Meteorological Society,* 63, No. 268 (January 1937), 103-4. Sir Gilbert T. Walker and C. J. P. Cave have also contributed studies of great value on the physics of clouds. See also D. Brunt, "Natural and Artificial Clouds," *Ibid.,* 63, No. 271 (July 1937); and Cave, "A Remarkable Cloud Formation on September 26th, 1933," *Ibid.,* 60, No. 256 (July 1934).

* *Codes for Cloud Forms and States of the Sky,* Circular S, W. B. No. 1249. Quoted by permission of the Weather Bureau.

which supersede those shown in the International Atlas. The Warsaw abbreviations are as follows:

Cirrus	Ci	Stratocumulus	Sc
Cirrocumulus	Cc	Stratus	St
Cirrostratus	Cs	Nimbostratus	Ns
Altocumulus	Ac	Cumulus	Cu
Altostratus	As	Cumulonimbus	Cb

The Warsaw abbreviations and, in addition, the following four special abbreviations have been adopted by the Weather Bureau, effective January 1, 1939:

Cumulonimbus mammatus (Mammato cumulus)	Cm	Fractostratus	Fs
		Fractocumulus	Fc
		Altocumulus castellatus	Acc

SCIENTIFIC EQUIVALENTS OF POPULAR CLOUD NAMES

1. Bull's-eye: A patch of clear sky at the center of a cyclone; the "eye" of the storm; or a small isolated cloud seen at the beginning of a bull's-eye squall, marking the top of the otherwise invisible vortex of the storm.
2. Cat's-whiskers: The combinations cirrostratus and cirrocumulus are sometimes arranged in bands or in parallel belts crossing a part of the sky in a great circle.
3. Cloud banner: A caplike cloud crowning a mountain summit or another cloud, especially a mass of cumulonimbus; a bannerlike cloud streaming from a mountain summit.
4. Cloud street: A term employed by glider pilots to denote clouds possessing upward currents suitable for gliding. As a rule there is sufficient rising air under a cumulus cloud to enable a pilot to reach considerable heights above the surface. In this manner upward currents of 12 feet per second have often been noted; currents of from 6 to 9 feet per second are very frequent. Cumulus in long rows, and often staggered, are well known to have rising air currents beneath them.
5. Festoon cloud: Mammato cumulus. A form of cloud showing sacklike protuberances.
6. Fogbow: A colorless, or almost colorless, rainbow formed in a fog.
7. Funnel cloud: Tornado. A pendulous, more or less funnel-shaped

cloud, the product of a violent vortex in the atmosphere, known as a tornado in our latitudes and as a violent thundersquall in West Africa.

8. Lenticular cloud: A cloud having approximately the lenticular form of a double-convex lens. They represent a transitional stage in the development or disintegration of one of the more well-known cloud types. Often induced by mountain ranges, they form at the crests of standing waves in the atmosphere.
9. Line squall cloud: Cumulonimbus arcus. Mean lower level, 1,600 feet (500 meters).* A variety of cumulonimbus stretching like a long line or arch across the sky. A line of squalls and thunderstorms, more or less continuous, marks the position of an advancing cold front.
10. Mackerel sky: Cirrocumulus. Mean lower level, 20,000 feet (6,000 meters). An area of sky covered with cirrocumulus or altocumulus clouds, when the clouds assume the patterns observed on the backs of mackerel. Small globular masses or white flakes without shadows, or showing very little shadow, arranged in groups and often in lines. Small altocumulus may also be mackerel sky. It is sometimes called "mottled sky."
11. Mare's-tails: Tufted cirrus; cirrus appearing in long slender streaks. Mean lower level, 20,000 feet (6,000 meters).
12. Mother-of-pearl clouds: About three times the height of the highest cirrus, float richly iridescent masses of cloud showing lovely rainbow tints. The mother-of-pearl clouds must not, however, be confused with the so-called Noctilucent clouds, luminous cirruslike clouds supposedly of dust origin, shining with reflected sunlight and roughly 50 miles above the surface. Still occasionally reported, the latter were observed during several summers after the eruption of Krakatoa in 1883. They are also known as nacreous clouds.
13. Mountain fog: Low-lying stratus clouds. Mean upper level, 6,500 feet (2,000 meters). The low height of stratus distinguishes it from nonfibrous altostratus. Its mean lower level is close to the surface. When stratus is broken up into irregular shreds in a wind, or by summits of mountains, it may be distinguished by the name fractostratus. Even though a uniform layer of cloud resembling a fog, stratus may be undulated or festooned in appear-

* The estimated mean heights of the various cloud types indicate that clouds frequently appear at greater or lesser heights than those mentioned.

ance. When blown in from a lower to a higher elevation, as at the base of a mountain, stratus is called "mountain fog."

14. Rain clouds: Altostratus, stratus, and stratocumulus frequently yield rain or snow, while precipitation occasionally reaches the ground from altocumulus and cumulus.
15. Scarf cloud: A thin cirruslike cloud often seen draping the tops of tall cumulonimbus clouds.
16. Scud: Either fractocumulus or fractostratus. Shreds or small detached masses of cloud moving rapidly below a compact deck of higher clouds.
17. Smog: A term used by aviators to describe the combination of smoke and fog frequently encountered over large cities.

An amusing use of the term is found in Alexander McAdie's description of the dense fog of March 1929 along the Atlantic seaboard:

> Until near noon on Saturday the 16th, the fog was so dense that objects ten yards distant were swallowed up in the murk. This homebrewed *smog* (smoke-fog) was as murky as a London "pertickler." New Yorkers rising from their beds on each of the three mornings found it unnecessary to pull down the window shades. (In the metropolis it is customary to do so, when starting to dress.) *

18. Thundercloud: Cumulonimbus. Upper level equal to that of cirrus; mean lower level, 1,600 feet. Heavy masses of cloud rising in the form of mountains, turrets, or anvils, generally surrounded by a sheet or screen of fibrous appearance ("false cirrus," tops of cumulus clouds blown off by the storm wind), and having at its base a mass of cloud similar to nimbostratus.
19. Wool-pack: Cumulus. Mean upper level equal to that of cirrus. Thick clouds, the upper surface of which is dome-shaped and exhibits protuberances, while the base is horizontal. The towering summer "cloud with the silver lining."

* Alexander McAdie, "The Control of Fog." In *Scientific Monthly,* July 1931, p. 33.

Courtesy, U. S. Weather Bureau

CIRRUS. This feathery ice cloud at the top of cloudland can be recognized by its delicate white composition, of fine fibrous texture. Except when unusually dense, it is transparent, and cirrus clouds passing across the face of the sun scarcely diminish its brightness.

In our latitudes, cirrus clouds are often visible in the early morning. If they dissolve as the sun rises and warms the air, the day will be fair; but dense, bunched cirrus may herald rain. Being usually composed of ice crystals—sometimes collected into small snowflakes—cirrus does not lead to rain. It does, however, sometimes indicate the direction of a storm center.

Mean lower level, 20,000 feet (6,000 meters). In some latitudes cirrus may reach 26,000 to 30,000 feet, but it cannot pass the tropopause.

Photo by W. S. Davis; Courtesy, U. S. Weather Bureau

CIRRUS BANDS. Among its many varied forms, cirrus sometimes spreads across the sky in bands like meridians on a celestial globe. In the middle latitudes these cirrus bands are 6 to 7 miles above sea level; near the Equator they are half again as high.

The clouds are arranged in parallel belts, and cross part of the sky as arcs of great circles; but by an effect of perspective, they appear to converge at a point on the horizon—or, if sufficiently extended, at a point on the opposite horizon also. This formation is known as "polar bands" or "Noah's Ark" because the bands resemble the ribs of a colossal canoe in the sky, narrow at both ends and broad in the middle.

Cirrostratus and cirrocumulus are sometimes arranged in similar bands.

Cirrus assumes many shapes, from the swirls and ringlets for which it was named, to bands. This picture shows cirrus in parallel trails and small patches.

Courtesy, U. S. Weather Bureau

PLUME CIRRUS, "Locks of the Approaching Storm."
This photograph, taken at Cheyenne, Wyoming, on August 5, 1933, gives an excellent close-up of the plumelike form of cirrus. This beautiful creation may be further distinguished by the dazzling, silky whiteness of its edges.

Photo by F. Ellerman; Courtesy, U. S. Weather Bureau

DELICATE CIRRUS. These irregularly arranged filaments of cirrus are oriented in various directions. At the lower right they show a tendency to merge into cirrostratus, a uniform sheet of high cloud which often covers the sky completely, giving it a milky appearance.

What can be said of the transparency and colors of delicately fibrous cirrus is also true to a great extent of cirrostratus, both when spread out in a thin whitish sheet of cloud and when formed like a tangled web.

Cirrus, however, occurs more frequently and is more conspicuous than cirrostratus, appearing in a multiplicity of beautiful forms at all seasons of the year. The capricious pageantry of the sky becomes then a great drama of Nature.

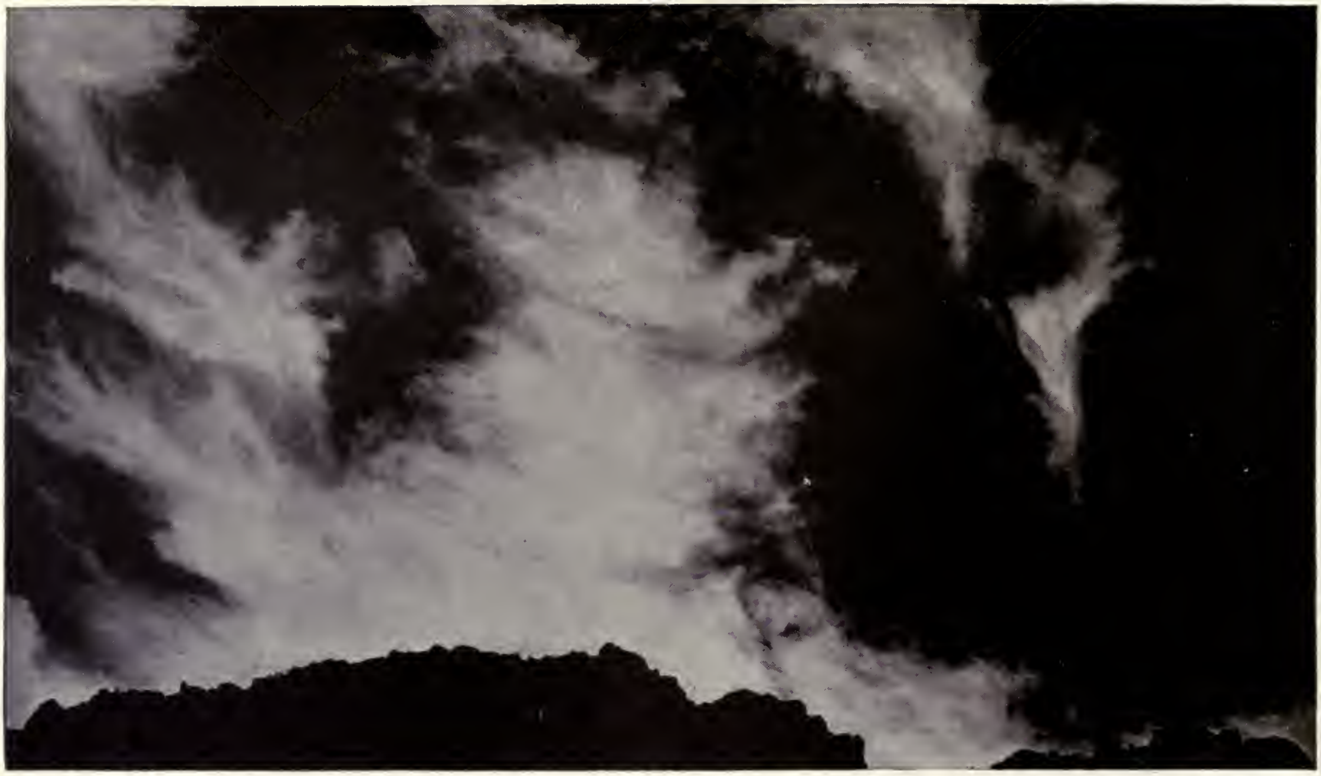


Photo by W. S. Wood; Courtesy, U. S. Weather Bureau

TUFTED CIRRUS. Not solar prominences, but cirrus increasing, generally in the form of a small point or tuft. Often occurs on the front of a typical cyclone.

Photo by Rev. L. Rades, S.J.; Courtesy, U. S. Weather Bureau

CIRRUS UNDULATUS. Delicate detached clouds arranged in waves. As a rule they exist in below-zero temperatures.

Courtesy, U S. Weather Bureau

CIRRUS DENSUS, OR FALSE CIRRUS. Photographed from the Ebro Observatory, Tartasa, Spain.

Photo by Maj. R. S. Owens; Courtesy, U. S. Weather Bureau

CIRRUS TRAIL. A trail of cirruslike clouds formed by condensation of vapor from the engine exhaust of an airplane in the cold, humid air of great heights.

Photo by Hans Groenhoff

CIRRUS DENSUS, OR FALSE CIRRUS. Dense, bunched cirrus of thunderstorm origin, cirrus densus are the tops of cumulus which are blown off by high winds preceding a storm. In thundery or squally weather, this particular kind of cirrus is often seen originating from the anvils of cumulonimbus. It is sometimes called "false cirrus" because it is denser and lower than other forms of cirrus. False cirrus are composed of the debris of the upper frozen parts of the thundercloud.

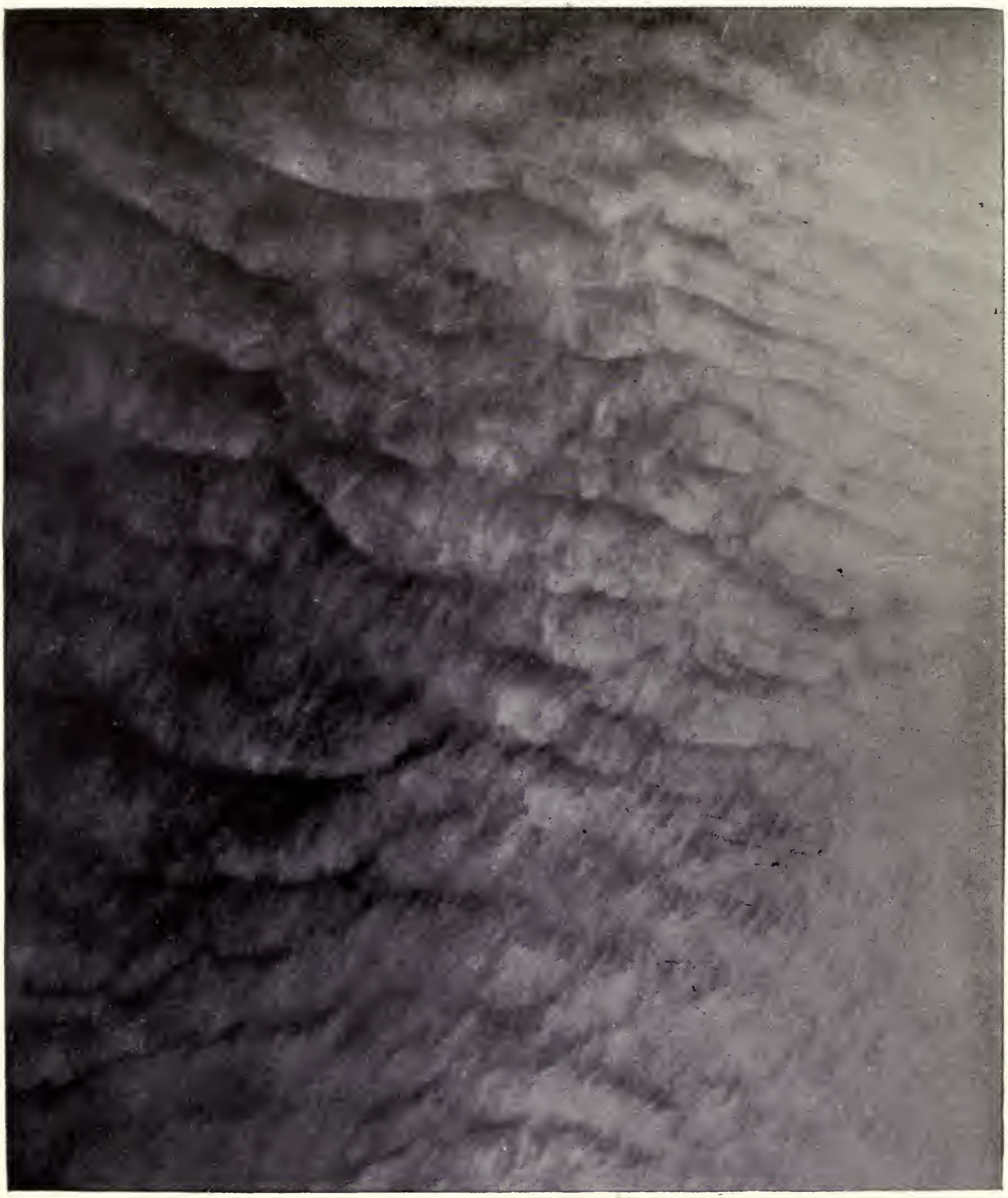
In the photograph above, the edges of the anvil can be seen to be fraying out into cirrus forms. Notice also the clearly defined edges of the lower parts of the cloud—a sign of cooling by elevation. This picture of towering cumulonimbus—it might well be labeled "Pillar of Cloud by Day"—gives an excellent impression of the depth and thickness of these clouds.

Photo by Pan American Airways; Courtesy, U. S. Weather Bureau

CIRROSTRATUS, "Curtains of the Coming Night."

The second highest cloud, cirrostratus, is a thin whitish sheet, sometimes covering the whole sky like a veil—known as "cirrus haze"—and giving it a milky appearance; at other times showing a fibrous structure like a tangled web. Cirrostratus often produces halos around the sun or moon, from which we know that it is composed of ice crystals. Sometimes the crystals cohere into snowflakes, so that the cloud is actually a snowstorm in the air. Thin cirrus overcast suffused with the glowing colors of dawn may be seen at a ceiling of about 20,000 feet.

In this photograph, cirrus and cirrostratus are seen in the upper layer behind the massive cumulus which already shows signs of changing into cumulonimbus. Observe the scarf of false cirrus at the top left of the cumulus cloud. In the lower layer behind the cumulus can be seen the top of stratus or stratocumulus. An early change in weather is the outlook.



Courtesy, U. S. Weather Bureau

CIRROSTRATUS UNDULATUS. A close-up view of the undulated form, photographed October 12, 1932. White, fibrous, and billowy, it resembles an extensive sheet of cirrus densus, from which it may originate.

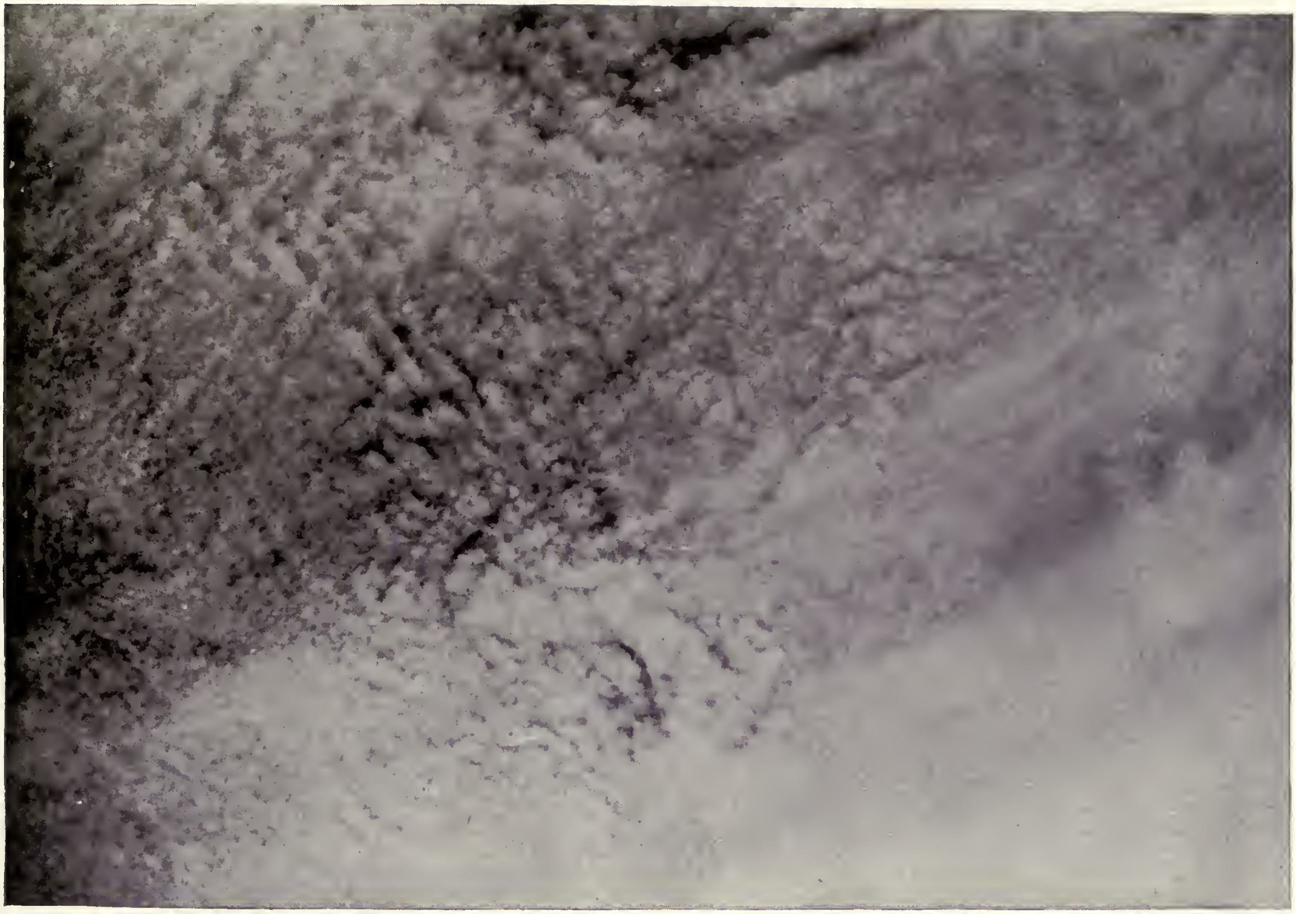


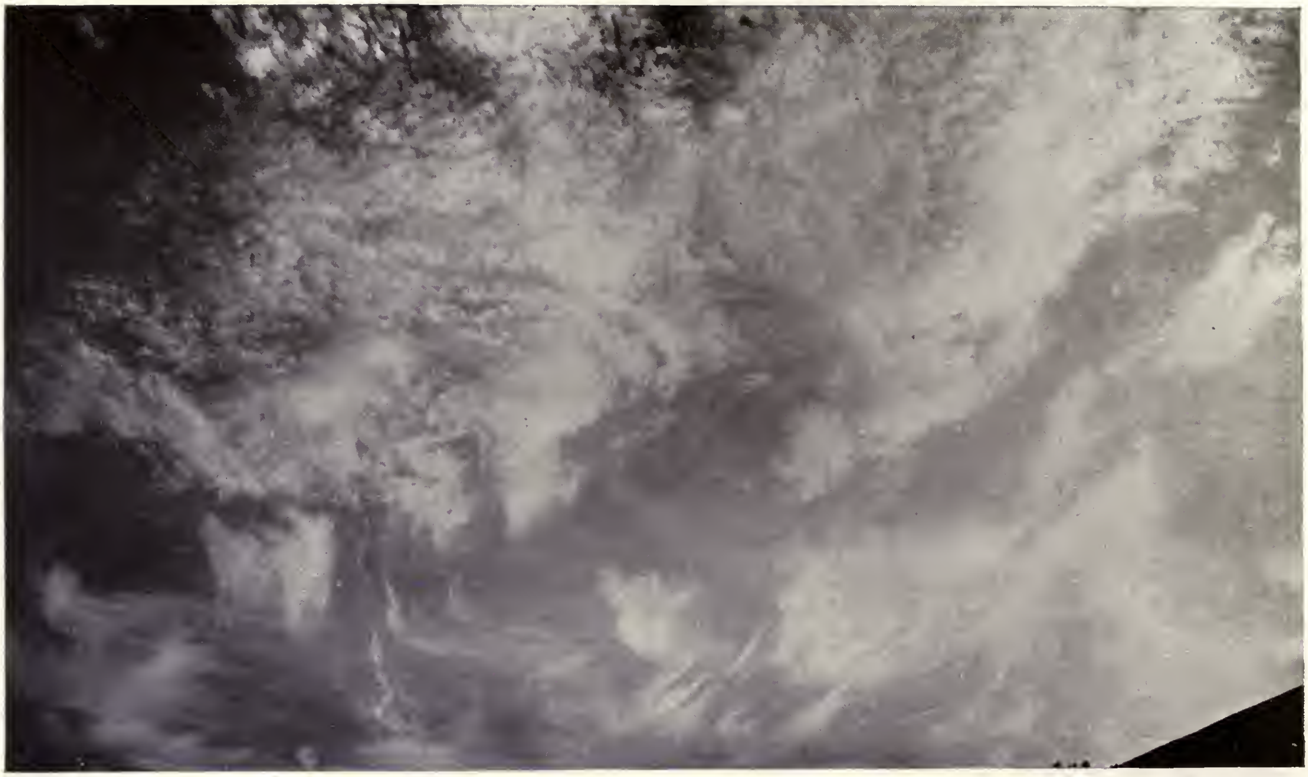
Photo by H. T. Floreen; Courtesy, U. S. Weather Bureau

CIRROCUMULUS. "Mackerel Sky." Unshadowed, or at most slightly shadowed, cirrocumulus may be seen either in groups or in a straight line. Usually this type of fleecy cloud, sometimes called "speckle cloud," is recognizable grouped in whitish balls or grayish rounded masses in a mackerel sky, the different balls frequently so close together that their edges meet.

The cloudlets, or closely packed white flakes of cloud, consist of microscopic crystals of ice. At 20,000 to 30,000 feet, they are emissaries of the warm front. On the approach of a storm they thicken into cirrostratus, which in turn thickens and lowers to altostratus.

Cirrocumulus is evolved from degeneration of a mass of cirrus or a sheet of cirrostratus. The transition from cirrus to cirrocumulus is apparent at the center of the lower margin of the above picture, taken on January 5, 1933. At the lower right there is some cirrus.

Mean lower level, 20,000 feet (6,000 meters).



Courtesy, U. S. Weather Bureau

CIRROCUMULUS WITH TUFTED CIRRUS. The transition from cirrus to cirrocumulus is evident, with cirrocumulus predominating.

Photo by W. J. Humphreys; Courtesy, U. S. Weather Bureau

ALTOCUMULUS. A close-up of the cloudlets which make up "mackerel sky." The fine globular masses are not unlike the patterns on the skins of mackerel.

Courtesy, U. S. Weather Bureau

MACKEREL SKY. The cloudlets of cirrocumulus or small altocumulus, arranged in groups of minute globular masses and often in lines or waves, make the fish-scale design which inspired the couplet:

"Mare's-tails and mackerel scales
Make lofty ships carry low sails."

Mackerel sky is watery in appearance—the true rain type invariably followed by rain or snow. It sometimes precedes thunderstorms. This photograph shows thin altostratus (lower right) transforming to growing altocumulus, which merges into dense altostratus (lower left).

These fine globular masses of "heaped-up cirrus" likewise resemble the ripples in sand at the seashore, with larger waves crossed diagonally by smaller ripples. The cloudlets are formed by many tiny convections in a thin, unstable layer of air.

Photo by G. A. Latt; Courtesy, U. S. Weather Bureau

ALTOCUMULUS—"NURSLINGS OF THE SKY," "The Herringbone." Unlike the cloudlets of cirrocumulus, the larger whitish or grayish balls of altocumulus show distinctly shadowed portions. The balls of cloud, frequently so close together that their edges touch, are grouped in flocks like a herd of cloud-sheep, or in rows in one or two directions like a herring-bone pattern. Toward the center of the pattern the balls are usually larger and more compact, passing into stratocumulus; on its edges they are delicate and wispy, passing into cirrocumulus. Viewed from a long time interval, altocumulus are often degenerate clouds. Certain types originate in dissipating altostratus, frequently appearing in more than one layer. Mean upper level, 20,000 feet (6,000 meters); mean lower level, 6,500 feet (2,000 meters).

Courtesy, U. S. Weather Bureau

ACTIVE, OR TRANSFORMING, ALTOCUMULUS. Usually precedes rain. A fairly common sequence is: altocumulus, usually in more than one layer, then altostratus, then nimbostratus and rain.

Photo by W. S. Wood; Courtesy, U. S. Weather Bureau

ALTOCUMULUS BANDS. These parallel lines of cloud pillars appear to emanate from a central point of origin. Compare the equally beautiful "band" pattern assumed by cirrus.

Courtesy, U. S. Weather Bureau

ALTOCUMULUS UNDULATUS. The undulated form, locally more or less scaly. The layer is of irregular thickness, with signs of evaporation in places.

Photo by Sir David Wilson-Barker; Courtesy, U. S. Weather Bureau

ALTOCUMULUS. "The Herringbone." Small altocumulus such as this are sometimes confused with cirrocumulus. They can be distinguished by the fact that altocumulus clouds are shadowed. Even if there were no shadows, the presence of coronas near the sun or moon would distinguish small altocumulus from cirrocumulus.

Small clouds are produced by shallow instability in the air; deep instability gives rise to the anvil head and the thunderstorm. If altocumulus appear healthy, in all probability they will develop into thunderstorms; but if they are tiny and stunted, they will never attain any great size. They will either dissipate slowly or descend to the level of stratus. In a layer of air close to the earth's surface, the most frequent regions of instability are water regions in winter and land regions in summer.

Photo by F. Ellerman; Courtesy, U. S. Weather Bureau

ALTOSTRATUS. "Whirling Altostratus." A dense sheet or thick layer of dull gray or blue, "whirling altostratus" is composed of innumerable threadlike parts. This form shows gradual transitions to cirrostratus in what meets the eye as a beautiful whirling creation. Cirrostratus and fibrous (threadlike) altostratus may originate from thunderstorm tops.

The picture above shows thin, undulated altostratus forming above a layer of fog or stratus. Such thin altostratus is distinguishable from cirrostratus by its grayness, or by the presence of coronas or iridescence.

Mean lower level, 6,500 feet (2,000 meters); mean upper level, 20,000 feet (6,000 meters).

Courtesy, Pan American Airways System

SUNSET VIEW OF ALTOSTRATUS. An altostratus sheet reflects the sunset of a thundery, stagnant sky. Note the sunbeams slanting through lower clouds and the scattered lenticular cloud formations.

It is difficult to draw a clear-cut line between broken altostratus and dense cirrus. In some instances altostratus showing signs of instability at high levels is the product of the anvils of cumulonimbus. Finally these same clouds may form into a continuous uniform sheet, often broken or irregular, especially in hilly country.

Altostratus proper, however, is a thick gray or bluish-gray sheet which may be either a compact dark-gray mass of fibrous structure or a sheet thin enough for sunlight or moonlight to penetrate dimly, as through ground glass. In the photograph above, the sunlight is bursting through an exceedingly thin spot in the veil.

If its base lies below 6,000 feet, a cloud of this appearance is classified as stratus or stratocumulus—i.e. stratus exhibiting some tendency toward a cumulus-type base and top. Altostratus affords a good high ceiling for aircraft.

Photo by C. F. Brooks; Courtesy, U. S. Weather Bureau

MORNING VIEW OF ALTOSTRATUS. Typical thick altostratus, photographed from Mt. Washington.

Courtesy, U. S. Weather Bureau

MIDDAY VIEW OF ALTOSTRATUS. Turbulent altostratus with fog. The diffuse whitish veil at the top left exhibits tangled fibers.

Photo by W. S. Davis; Courtesy, U. S. Weather Bureau

STRATOCUMULUS ROLLS. The photograph was taken (looking south) at Orient, Long Island, with a strong east wind at the surface.

Courtesy, U. S. Weather Bureau

ALTOCUMULUS RIPPLES WITH STRATUS AND FOG BELOW NIMBOSTRATUS. Stratus, stable and relatively static, resembles fog.

Photo by W. J. Humphreys; Courtesy, U. S. Weather Bureau

STRATOCUMULUS. Lumpy rolls of cloud, dull gray and noted more particularly in winter, stratocumulus can be seen stretching in waves over the entire canopy of the sky. The clouds form at about noon and disintegrate by night. Stratocumulus is distinguishable from cumulonimbus by its ball-like or rolled form, and because it tends not to bring rain. At times, however, it assumes a lenticular form a few hours before rain. Low stratocumulus clouds are windy but not dangerous, and may be seen scudding before a west wind. Ragged stratocumulus rolls below fibrous altostratus are characteristic of breaking clouds in the rear of a cyclone.

Clouds which develop turreted tops and may finally grow into cumulonimbus—namely, stratocumulus or altocumulus—are seen most often at night or over the ocean.

Mean upper level, 6,500 feet (2,000 meters); mean lower level, close to the surface.

Photo by B. A. Thompson; Courtesy, U. S. Weather Bureau

STRATOCUMULUS CUMULOGENITUS. This type of stratocumulus, as its name implies, is formed from cumulus. In this picture the tops of cumulus are spreading out at the close of day to form opaque layers of stratocumulus. The final step in the process is the melting away of the bases of cumulus or cumulonimbus and the thinning of stratocumulus. Clouds formed in this way may show a mammatus structure.

The photograph on the title page of the book is a similar one of stratocumulus vesperalis, which is formed by the flattening of cumulus, and occurs in the evening. The tops of cumulus subside and flatten, and the bases spread out. Parts of the cumulus are still visible in the picture. At the top is stratocumulus formed by degeneration of another mass of cumulus. (Note also the crepuscular rays).

Photo by Dr. G. A. Clarke; Courtesy of U. S. Weather Bureau

STRATUS. Stratus is lifted fog in a horizontal stratum, a uniform layer of cloud resembling a fog but not resting on the ground.

A complete absence of details of structure differentiates stratus from other compact cloud forms. Thin, undulated altostratus may form above a layer of fog or stratus. Turbulence imparts to the top surface an appearance corresponding to that of most cloud sheets at all heights. Stratus often forms only on the mountainsides and not in the free air. Or, as in the picture above, it may be a uniform sheet below the level of a hilltop, with shreds of fracto-stratus along the hillside.

Stratus is common in tropical air at all seasons. In winter it often develops over land, and may drag on the ground in the form of mist. In summer it develops over the seas and may be seen drifting inland on a summer night. When a damp layer moves in from the sea, it may develop over land.

Mean upper level, 6,500 feet (2,000 meters); mean lower level, close to the surface.

Photo by Hans Groenhoff

NIMBOSTRATUS. Nimbostratus is already entering the picture below a layer of altostratus which covers practically the whole sky. From the ground it is impossible to make out definite details in the make-up of nimbostratus; it is a low, amorphous rainy layer, dark gray and nearly uniform, seeming feebly illuminated from inside. It always shows some contrasts and some lighter, transparent parts. When it gives precipitation, it is in the form of continuous rain or snow. But precipitation is not a sufficient criterion to distinguish nimbostratus; there is often precipitation which does not reach the ground, in which case the base of the cloud is always diffuse and looks "wet" on account of the general trailing precipitation, and the cloud's lower surface cannot be determined. Mean upper level, 6,500 feet (2,000 meters); mean lower level, close to the surface.

Official Photograph, U. S. Army Air Forces

CUMULUS. "The Wool-Pack." A white-topped, peaked, and bulbous mass of summer cloud, the wool-pack extends to a height of 8,000 to 9,000 feet in midsummer, with its flat base only about 1,600 feet above the earth. Its mean altitude is about 4,600 feet. In spring and early summer, cumulus is very much lower than in midsummer, but its depth then is not half so great. In our latitudes it rarely exists in winter because of the cold.

Like other isolated heap clouds, cumulus has a vertical development during its formation and spreads out when dissolving. The true cumulus shows a sharp upper and lower border. It is often torn by strong winds, and the detached parts, fractocumulus, present continual change.

Cumulus clouds develop in the morning after a layer of stratocumulus has moved in from the sea in the night. A common cloud combination is cumulous ascending from beneath and piercing layers of stratocumulus.

Mean upper level, that of cirrus; mean lower level, 1,600 feet (500 meters).

Photo by Hans Groenhoff

CUMULUS. "The Cloud with the Silver Lining." When the cloud is opposite the sun, the surfaces facing the observer are brighter than the margins of the protuberances. When the light falls aslant, the cloud throws a deep shadow; when the cloud is on the same side of the observer as the sun, it appears dark with bright edges, from which it gets the name "cloud with the silver lining."

Cloud heights may be roughly judged by the brightness of the clouds. The high ones are brighter because they best reflect sunshine.

When cumulus appear in the morning, their temperature may differ little if any from that of the air around them. As a rule, clouds which tower up rapidly are slightly warmer than their environment; whereas the flat fair-weather type are colder than the adjacent air.

Photo by Hans Groenhoff

HIGH-PILED FLUFFS OF SUNLIT RADIANCE. Distinguished by its dark, flat base, this typical summer cumulus, seen at close range, may change dramatically into a thunderhead. The wind is gusty and a shower threatens. Note the silver-lining effect along the upper margins and the small areas of light showing that the cloud is thin in some spots.

Official Photograph, U. S. Army Air Forces

CUMULUS HUMILIS. Flat cumulus without towers or protuberances are called "cumulus humilis," or fair-weather cumulus. The division of cumulus into cumulus humilis and cumulus congestus is an example of the classification of clouds into species and varieties. Like cumulus congestus, fair-weather cumulus seldom cover more than half the sky. In this picture they are visible in a shapeless and rather dense ragged layer of low cloud, in which fractocumulus is also present.

Cumulus humilis, too, signal the airplane pilot what the air streams are doing at various levels; cumulus point to rough air with vertical currents. Icing on an aircraft is more severe in cumuliform clouds than in stratiform because the large droplets of which they are composed form abundant ice; whereas the small droplets of stratiform clouds tend to flow around the wings of the airplane.

Official Photograph, U. S. Army Air Forces

CUMULUS CONGESTUS. The cloud in the foreground, showing a curl on the right, is the top of cumulus congestus, distended and sprouting cumulus whose domes have cauliflower swellings. This cloud has not reached the cumulonimbus stage; the ones in the background have.

In the cold air mass behind a cold front are the fleecy cumulus of fine weather, thick clouds with vertical development. Being of great vertical depth, the tops of the clouds may extend 2 or 3 miles above their relatively flat bases. In the background, or direction of flight, may be seen anviled cumulonimbus with summits rising in the form of mountains or towers, and surrounded by false cirrus. Fractocumulus and altocumulus can be seen in the area between the large cumulus in the foreground and the cumulonimbus in the rear. Between the two cumulonimbus, and to the extreme left, are traces of lenticular formations.

These clouds are indicative of active convection on a warm afternoon, when rising columns of heated air form cumulus clouds at their tops, like puffs of steam from a locomotive.

Official Photograph, U.S. Army Air Forces

CUMULUS IN TRANSITION. Cumulus floating along at 14,500 feet. The high, ever-changing tops resemble huge cauliflowers or great piles of cotton. They are formed by vertical currents of warm air cooled adiabatically as they rise; the nearly horizontal base of the cloud marks the elevation at which the ascending air is cooled below the dew point.

The clouds in this photograph seem to be in the process of transition to cumulonimbus. An anvil is beginning to form, and the upper right edge shows signs of fraying out into cirrus. Presently a cirrus scarf will appear on the left side of the anvil. Masses of cumulus, however heavy, may not be classified as cumulonimbus unless their tops in whole or in part are transformed, or in process of transforming, to a cirrus mass.

Courtesy, U. S. Weather Bureau

CUMULUS ROLL. Altocumulus and a tracing of cirrus above a cumulus roll, photographed September 24, 1912. Cumuliform clouds are characteristically distinct and separated by clear spaces.

Courtesy, U. S. Weather Bureau

FAIR-WEATHER CUMULUS. As they traverse sun-scorched ground, low-lying cumulus humilis may change into small thunderheads and shed rain.

Official Photograph, U.S. Army Air Forces

CUMULUS MERGING INTO CUMULONIMBUS. A typical fair-weather sky over the California Desert. It indicates the approach of a cold front.

Official Photograph, U.S. Army Air Forces

CUMULUS, SEVERAL TYPES IN LAYERS. Stratocumulus, altocumulus castellatus, and thunderhead behind billowy cumulus of summer.

Official Photograph, U. S. Army Air Forces

CUMULONIMBUS. This is the thundercloud, the shower cloud. Cumulonimbus is composed of heavy masses of cloud rising like mountains, anvils, or towers; surrounded mostly at the top by a veil or screen of fibrous cirrus densus, and below by nimbuslike masses of cloud. They are thick clouds, the upper surfaces of which are dome-shaped and show protuberances. They are thicker than any other cloud forms. In his "Lehrbuch der meteorologie," Hann gives their average thickness as 2,070 meters (6,728 feet) and their greatest measured thickness as above 4,600 meters (14,950 feet). Local showers of rain or snow generally fall from the bases of cumulonimbus—sometimes hail or sleet. The front of a thunderstorm cloud of wide extent may show a great arch stretching across a portion of the sky and uniformly lighter in color. Low cumulonimbus and cumulus are characteristic of spring. The picture above shows cumulonimbus in the early stages of growth.

Official Photograph, U.S. Army Air Forces

ANVIL TOP OF CUMULONIMBUS. Clouds with anvil tops build up when warm, moist air is pushed upward as cold air slides in below and moisture condenses. At a height of a few hundred feet, a tongue of cold air may penetrate a warm mass running thus in advance of the main body of cold air, which eventually displaces completely the warm air from the surface up. The violent ascending currents within the cloud explain the considerable heights of cumulonimbus.

The line of cumulonimbus in the background of the picture indicates where a cold air mass is pushing under warm air. Cumulus congestus in the foreground may grow rapidly to great heights and develop into thunderstorms in summer and showers or snow squalls in winter.

With the cirriform parts of anvils reaching to the level of high cirrus, cumulonimbus is often a regular factory of clouds. The principal mass may be only one of several cumulonimbus clouds in the vicinity.

Courtesy, U. S. Weather Bureau

CAULIFLOWER THUNDERHEAD. This lonely voyager in immensity has the typical cauliflower structure, showing internal motion and turbulence. Cirrus densus, or false cirrus, surrounds the anvil of a huge cumulonimbus, of which only the top shows in the picture. The anvil is fully developed, and its edges are frayed out. Sometimes the upper margins of an anvil, instead of being fringed with filaments similar to cirrus, retain the compact shape of cumulus.

The vertical extent of both cumulus and cumulonimbus is much greater than that of other cloud types. Since both are produced by condensation of moisture from rising air currents, the height of their bases—on the average rather less than a mile—varies widely with the temperature and humidity of the lower air. Marked variations in rainfall beneath a thunderhead are owing to violent vertical winds, and to a duplication of rain sources inside the cloud.

Photo by C. F. Talman; Courtesy, U. S. Weather Bureau

CUMULONIMBUS SHOWERS. Cumulonimbus shower clouds showing great masses of cloud rising like mountains, and a base that looks like a ragged mass of nimbostratus. Photographed in April 1926. A very great depth of cloud, such as the above, is usual over areas where cold and warm air-mass clouds merge into a solid overcast. When cumulonimbus covers nearly all the sky, the base alone is visible and resembles nimbostratus with or without fractostratus or fractocumulus below.

Photo by Hans Groenhoff

CUMULONIMBUS. The thunderhead which harbors thunder, hail, and powerful updrafts. Note the false cirrus breaking off from the top, and the flat base of the thunder cloud.

Photo by W. J. Humphreys; Courtesy, U. S. Weather Bureau

CUMULONIMBUS. The rain cloud has a dark curtain hanging down toward the earth.

Official Photograph, U. S. Army Air Forces

FRACTOCUMULUS. Cumuliform clouds are often torn by strong winds, and the detached parts, fractocumulus, present continual changes. The photograph above, taken in the vicinity of Miami, Florida, shows fractocumulus driven by the wind, with altocumulus and heavy cumulus in the background. The shadows are light, indicating that the clouds are thin.

Fractocumulus is a fair-weather cumulus, and often appears as a ragged cloud in the wake of a cyclone. It consists of scattered masses with a flat, deflated appearance, and the horizontal extension is greater than the vertical.

Fractocumulus traversing the skies in fair or normally quiescent conditions must not be confused with those which form below nimbostratus or altostratus and are seen below heavy and swelling cumulus or cumulonimbus. These latter are characteristic of bad weather.

Official Photograph, U.S. Army Air Forces

FRACTOCUMULUS UPWIND. Vertical velocity gradient.

Official Photograph, U.S. Army Air Forces

FRACTOCUMULUS CROSSWIND. Clouds moving to the left. Vertical velocity gradient.

Official Photograph, U.S. Army Air Forces

FRACTOCUMULUS AND CUMULUS DOWNWIND. Vertical velocity gradient T_G below, I_S above. Ragged, scudding squall clouds signify the passage of a cold front.

Official Photograph, U.S. Army Air Forces

FRACTOCUMULUS AND STRATOCUMULUS, growing out of cumulus and cumulonimbus. At the wind-torn edges of clouds, shafts of sunlight gleam in falling rain.

Photo by H. T. Floreen; Courtesy, U. S. Weather Bureau

FRACTOCUMULUS. Another view of fair-weather cumulus torn by strong winds.

Photo by C. A. Gilchrist; Courtesy, U. S. Weather Bureau

CUMULUS ROLLS. The roll cloud is a special form of fractocumulus and is sometimes dangerous to aircraft because of severe turbulence.

Photo by Harold Photographic Studio; Courtesy, U. S. Weather Bureau

MAMMATO CUMULUS. This unusual cloud formation covered four tenths of the sky during thunderstorms which preceded a warm front at the ground.

Courtesy, U. S. Weather Bureau

MAMMATO ALTOSTRATUS in an evening sky. Photographed at St. Joseph, Mo., at 7:50 p. m., June 17, 1932.

Photo by H. T. Floreen; Courtesy, U. S. Weather Bureau

MAMMATO CUMULUS—FORERUNNER OF THE TORNADO. "Festoon Cloud." Mammatus is a descriptive term applicable to all clouds whose lower surfaces form pouches, or breasts—heavy sack-shaped protuberances covering its base and hanging downward. This rather rare form is known in parts of England as "rain-balls" and in Scotland as the "pocky" (baggy) cloud. It is found especially in stratocumulus and cumulonimbus, either at the base or, even more often, on the lower surface of anvil projections. It is also found, though rarely, in cirrus, probably when cirrus has originated in the anvil of a dispersing cumulonimbus. Mammato cumulus, associated with thunderstorms, is a forerunner of the tornado and sometimes forms at the border of a thunderstorm followed by a short wind squall.

Photo by Pan American Airways System

ALTOCUMULUS CASTELLATUS. Castellated, or turreted, altocumulus are dense, fleecy cumuliform masses with more or less vertical development. Resting on a common horizontal base, which gives them a crenellated appearance, they are arranged in a line, as in the photograph, which shows detached masses of altocumulus castellatus and tall cumulus castellatus moving rapidly below a solid deck of higher clouds.

Observe the feathery cirrus and, underneath, the longitudinal formations in the process of lowering and transforming. (Transforming altocumulus precedes rain.)

Shading is plainly visible on the surfaces of the thicker cloudlets.

Photo by I. R. Tannehill; Courtesy, U. S. Weather Bureau

ALTOCUMULUS LENTICULARIS. Among the few distinct minor varieties of cloud recognized by meteorologists is the lenticular cloud, so named for its almond shape, resembling the cross-section of a double-convex lens. It may be seen at various heights in the free air, but generally over hills or mountains. It is a small cloud which remains almost stationary, and indicates the presence of a billow in the air stream, the moisture condensing at one edge of the cloud and dissolving at the other, which gives it a lenticular shape. The height of a lenticular cloud is apparently governed by the amount and distribution of humidity in the atmosphere. It frequently shows iridescence.

Sometimes this isolated cloud type is observed against a background of altostratus veil. Layer clouds of the altostratus type as a rule mark the temperature inversion existing when a warm air mass overruns colder air. In a layer of stable air, the decrease of temperature with height is slow—so slow that rising air, unless in great volume, cannot penetrate it to any extent. At the base of such a layer, lenticular clouds may be formed by the arrest of a small ascending cumulus cloud.

Photo by P. Harney; Courtesy, U. S. Weather Bureau

ALTOCUMULUS LENTICULARIS. Another striking modernistic photograph of a lenticular cloud. When a lenticular cloud is formed by the arrest of a cumulus, as described on the opposite page, it spreads out in the shape of a lens. The direction and strength of the wind determine whether the body of the cloud assumes a circular or a distorted form. A lenticular cloud may therefore be said to represent a transitional stage in the development or disintegration of one of the well-known cloud types. It forms at the crests of standing waves in the atmosphere, produced by the wind flowing over an uneven surface. Mountain peaks or ranges often cause such billows in the air. In these circumstances the cloud is fixed in position, being formed with condensation on the windward side and evaporation on the leeward, the wind and moisture in effect passing through it without moving it. Such lenticular clouds, capping standing billows in the air, may be seen at considerable heights above the earth's surface, instead of close to the ground.

Official Photograph, U.S. Army Air Forces

LENTICULAR CLOUDS. Lenticular clouds above and altocumulus castellatus or scattered cumuliform tufts, seen looking across cloud formations at Mt. Adams, Washington.

Photo by C. F. Talman; Courtesy, U. S. Weather Bureau

ATLOCUMULUS LENTICULARIS. Small, well-defined lens-shaped masses against a background of altostratus veil. Photographed April 1926.

Courtesy, U. S. Weather Bureau

ALTOCUMULUS LENTICULARIS, against a background of altostratus veil. Photographed October 31, 1932.

Courtesy, U. S. Weather Bureau

ALTOCUMULUS, rising over the summit of a hill in the shape of a sacklike protuberance, like smoke from the mouth of a ghostly cannon.

Photo by C. D. Walcott; Courtesy, U. S. Weather Bureau

BANNER CLOUD, over Mt. Assiniboine, Canada, July 1916. The banner cloud is also known as the "boa cloud" because it surrounds the peak like a feather boa.

Courtesy, U. S. Weather Bureau

LEVANTER CLOUD. This celebrated example of the banner cloud spreads over the Rock of Gibraltar when warm winds are forced upward and their moisture condenses.

Photo by C. F. Talman; Courtesy, U. S. Weather Bureau

TABLECLOTH OR CREST CLOUD. This famous cloud sheet rests on the ridge of Table Mountain, near Capetown, South Africa. It hangs down on each side of the flat top like a giant tablecloth. Photographed in January 1924.

Courtesy, U. S. Weather Bureau

BANNER CLOUDS, over the Siskyon Mts. in southern Oregon and northern California.

Courtesy, U. S. Weather Bureau

WAVE CLOUD, photographed 150 miles north of Ottawa, Canada. In the reflection of the sun to the left are the characteristic flattened globular and other characteristics of altocumulus.

Photo by H. T. Floreen; Courtesy, U. S. Weather Bureau

HORIZONTAL VORTEX CLOUDS, photographed at 8:35 a.m., February 22, 1936.

CHAPTER IV

HEIGHTS OF CLOUDS

The heights of clouds vary within wide limits. The high clouds, Family A, range between 20,000 and 30,000 feet; the medium clouds, Family B, between 6,500 and 20,000 feet; the low clouds, Family C, below 6,500 feet. The mean lower level of cirrus, or mare's-tails, the loftiest form of cloud, is about 20,000 feet, or 6,000 meters, though it has been observed at 26,000 to 30,000 feet in some latitudes. The mean upper level of cumulus, the wool-pack, is about that of cirrus. Cumulonimbus, the thundercloud, may soar as high as 6 or 7 miles. But its base may frequently be no higher than 2,300 feet, enswathing mountains and leaving the peaks quite dry. While the base of cumulus, notably cumulonimbus, may average 3,000 feet above the ground, the tops may tower to great heights. In midsummer cumulus may extend to a height of 8,000 or 9,000 feet, with its base only 1,600 feet (500 meters) above the ground. In spring and autumn these clouds are very much lower, and their depth not half so great. Cumulus rarely forms in winter because of the cold; low cumulonimbus and cumulus are characteristic of spring.

The different elevations of the several kinds of cloud depend chiefly upon the variations of the temperature in the atmosphere, all kinds being generally lower in winter than in summer. Not only are clouds lower in winter than in summer, but for the same reason they are lower in the polar regions than in the tropics. So low are they that some of the highlands of Asia are above the snow clouds, which has the important effect of making winter grazing possible in places. The greater the humidity, the less height to which a body of air must ascend to become cold enough to form a cloud. The winter humidity is high because the cold wet ground is constantly giving off moisture to the cool air above, which because of its coolness becomes more quickly saturated. If not too far above the horizon, individual clouds appear as though at different levels.

Cumulus, on the other hand, may spread out in thick fleecelike masses, and instead of towering like mountains, may approach the stratus form in wavy lines. Clouds in general, and at all levels, may indicate either a rolling-wave movement of the atmosphere or, more frequently, an appearance of a water surface broken by gusts of wind. Occurring over a wide range, from 2 to 3¾ miles, the altostratus type of cloud has no well-defined height of maximum frequency.

Cloud heights may be roughly judged by the brightness of the clouds—the high ones, which best reflect sunshine, are the brighter. The altitude may also be determined by noting the position of clouds over mountaintops of known elevation. When the observer is on his way up or down a mountain, he may frequently ascertain the height of a cloud whose base happens to be on a level with his own position.

TABLE OF CLOUD FAMILIES

Showing the Height and Range of Clouds according to the International System of Cloud Classification

Family	Height and Range	Abbreviation
A	HIGH CLOUDS: average lower level 20,000 feet (3 3/4 miles, 6,000 meters), extending sometimes to cloud ceiling 30,000 feet (5 3/4 miles).	
	1. Cirrus	Ci
	2. Cirrostratus	Cs
	3. Cirrocumulus—thin clouds, cotton- or flakelike, usually without shadows	Cc
B	MIDDLE CLOUDS: average lower level 6,500 feet (1 1/4 miles or 2,000 meters) to 20,000 feet	
	4. Altocumulus—sheep-back clouds	Ac
	5. Altostratus	As
C	LOW CLOUDS: average lower level from close to surface up to 6,500 feet	
	6. Stratocumulus—composed of laminae, globular masses, or rolls	Sc
	7. Stratus	St
	8. Nimbostratus—low amorphous and rainy layer, seemingly illuminated from inside. When it gives precipitation it is in the form of continuous rain or snow.	Ns
D	CLOUDS WHICH SHOW SIGNS OF BEING CARRIED UP VERTICALLY BY USING AIR CURRENTS:	
	The range of this family is any cloud level, from almost the lowest to the highest: average lower level from 1,600 feet (1/4 mile or 500 meters) to upper limit of Cirrus clouds.	
	9. Cumulus	Cu
	10. Cumulonimbus—Cauliflower towering, with Cirrus veils on top and great vertical development.	Cb

CLOUD RANGE CHART

I. Average Heights of Earth's Air Shells

Height Miles	Temperature (Fahrenheit)
10	—58
9	—60
8	—60
7	—58
6	—40
5 3/4 (30,000 ft.)	
5	—22
4	—4
3	14
2	32

STRATOSPHERE

Cold outer layer of the atmosphere, in which the temperature is almost constant with height. The temperature of this region decreases from the poles toward the Equator. The Stratosphere is free of clouds (except occasional dust clouds) and of strong vertical air currents. Because of this stable and cloudless state, it offers the prospect of future flight development.

TROPOPAUSE

This is the boundary layer between the Stratosphere and the Troposphere—the division, as it were, between the known and the uncertain. At this point the regular fall of temperature with height ceases and above this barrier to rising air, no clouds exist except occasional dust clouds.

Over the average of the earth the height of the Tropopause varies between 5 and 9 miles above sea level, depending upon latitude and season. It is higher over anticyclonic than over cyclonic areas, and higher in good weather than in bad. At the poles the fluctuation with seasons is slight; at the Equator scarcely any.

TROPOSPHERE

The Troposphere is the cloudland of earth's shallow atmosphere. It is the region of winds and clouds, cyclones and anticyclones. Clouds exist because they are comprised of aggregates of solid or liquid particles tending to fall rather than float.

Sea Level

CLOUD RANGE CHART

II. Average Heights of Clouds †

Miles	Feet	Family	
5 3/4	30,000		
	29,000		
	28,000		
	27,000	A	Cirrus * Wisps of light fibrous feathery cloud, usually in advance of a storm; do not condense into rain.
	26,000		
	25,000	A	Cirrus Densus * (False Cirrus) Stormy, or rough, sky; squally or thundery.
	24,000		Lenticular Altocumulus * Conditions windy.
	23,000		Cirrostratus If seen with halo around sun or moon, look out for bad weather.
	22,000	A	Cirrocumulus } "Mackerel sky." (Develops from Cirrostratus)
	21,000		
3 3/4	20,000	B	Altocumulus * } "Mackerel sky." (Develops from Cirrostratus)
	19,000	D	Cumulonimbus * Showers, thunderstorms, hail. Line squall. Bumpy air currents. Line squall cloud is a variety of Cumulonimbus.
	18,000		See ‡ below.
	17,000		
	16,000		
	15,000	B	Altocumulus. Windy weather: Huge globular masses close together, white or gray. Occur at heights of 2-4 miles. If turreted tops develop, look out for a chaotic thundery sky.
	14,000		
	13,000		
	12,000	C	Stratocumulus * A layer of patches dense enough to appear black, with blue sky between them. Conditions rough or bumpy for flying.
	11,000		
	10,000		
	9,000		
	8,000		
	7,000	D	Cumulus * (1) Domelike accumulations with blue sky between; rough to unsettled: Poor vertical visibility; squally. (2) Very flat cumulus (humulis) indicates fair weather.

Miles	Feet	Family	
1 1/4	6,500	B	Altostratus Increasing Altostratus often followed by steady precipitation.
	6,000		
	5,000		
	4,000	C	Nimbostratus *—or perhaps base of Cumulonimbus—Precipitation: snow or continuous rain in small drops.
	3,000		
	2,000	C	Stratus Fog, rain, sleet, or snow. Stratus, a low uniform sheet similar to fog but not reaching the ground, has a tendency to form in mountainous country, owing to turbulence.
1/4	1,600		

* Poor flying weather conditions, with a low ceiling and reduced visibility, are often indicated by the presence of clouds marked by an asterisk in the chart above. Cumulus may have its base at a low level and its top within cirrus level.

† Height of clouds, as taken from the International Atlas, are for temperate latitudes and are measured not from sea level but from the general level of land in the region. In certain cases there may be large departures from the mean level.

‡ Ninety per cent of the moisture content of the air and 50 per cent of the total weight of the air are within 18,000 feet of the earth's surface. A cubic foot of air at sea level weighs 1.22 oz.; or, in metric units, a cubic meter of air weighs 1.3 kilograms. A column of air from the earth's surface to the top of the atmosphere exerts a pressure on the surface equal approximately to the weight of a column of water 33 feet, or 10 meters, high; or to the weight of a column of mercury 30 inches, or 76 centimeters, high. Atmospheric pressure decreases with altitude.

CHAPTER V

MOVEMENTS OF THE AIR—CYCLONES AND ANTICYCLONES

WINDS—MASTER-MOLDERS OF CLOUDS

MAJOR WIND CIRCULATIONS: Regular air currents, or winds, keep the earth's atmosphere in a state of constant motion. The geography of the winds begins with the division of the earth into a number of permanent, though fluctuating, wind belts. On the Equator is the one known as the "doldrums." On either side of the doldrums come the trade winds, blowing continuously in the same direction except when briefly interrupted by the passage of a cyclonic disturbance, and they never subside to a calm. On the poleward sides of the trades, in each hemisphere, lie the belts called by Maury the Calms of Cancer and the Calms of Capricorn, also known as the "horse latitudes."

Still farther poleward, in the Temperate Zones of both hemispheres, the drift of the atmosphere is from west to east, and the winds are called the "prevailing westerlies." * Up to the highest cloud levels, this eastward drift is much interrupted by the passage of innumerable cyclones and anticyclones, attended by winds directed around their centers, hence blowing from all points of the compass.

The total catalogue of the winds is a long one, but these are the main air currents:

PLANETARY WINDS: These are the winds which occur on a planet such as ours, heated at the Equator and turning eastward on its axis. It follows naturally that a belt of low pressure should develop at the Equator, belts of high pressure in the tropical regions, and cups of low pressure at the poles. Thus calms prevail at the Equator and in the tropical regions, with wind blowing outward from the belts of high pressure, turning to the right in the Northern Hemisphere and to the left in the Southern.

THE DOLDRUMS: This is an equatorial belt of calms, character-

* The direction of the wind means the direction *from* which it is moving. If the wind is blowing from the southwest, its direction is said to be southwest.

ized by light baffling breezes, frequent dead calms, overcast sky, and heavy rains, often in the form of thunderstorms and squalls.

HORSE LATITUDES: Tropical high-pressure belts of calms, the horse latitudes are characterized by winds light in force and variable in direction. Calms are frequent; the sky is usually clear.

TRADE WINDS: Northeast in the Northern Hemisphere and southeast in the Southern, the trade winds blow from the horse latitudes toward the Equator. The reason for their veering from the straight north and south is the influence of the earth's rotation. They derive their name from the steadiness with which they blow, often from the same direction for about a week. They carry few clouds and cover nearly half the earth's surface. As they approach the Equator they increase in speed, and clouds become more frequent.

PREVAILING WESTERLIES: These are the winds of the Temperate Zones, which blow from the horse latitudes poleward. Their velocity is greater in the Southern Hemisphere than in the Northern, and they are sometimes called the "roaring forties."

LAWS OF WIND CIRCULATION: Two important laws, therefore, govern the circulation of winds around the earth:

1. Winds always tend to blow from a region of higher pressure (a "high") to one of lower pressure (a "low"), with a velocity which varies with the pressure gradient, as indicated by the closeness, or otherwise, of the isobars, or lines of equal barometric pressure, on a synoptic chart. When the difference in pressure ceases to exist, the wind ceases to blow.

2. On account of the rotation of the earth, winds do not flow directly from high to low pressure, but turn to the right of the pressure gradient in the Northern Hemisphere and to the left of it in the Southern, and follow the isobars approximately. The only winds which do not suffer deflection are those along the Equator. The deflective effect of rotation increases with latitude. Circumpolar winds are strongest in winter because both temperature and pressure gradients between the Equator and the Arctic are steeper in winter than in summer. Pressure belts and wind belts follow the shifting of the belt of greatest heat.

CYCLONIC WINDS: As a result of the excessive cooling of the northern continents during the northern winter, the north Pacific and Atlantic oceans are warmer than the northern continents, and are therefore centers of low pressure. About these cyclonic centers the winds spiral in a manner comparable to the circumpolar whirl. Whereas in our summer the heat equator migrates far into the heated continent of Asia, during our winter it moves southward, and over southern Asia and the northern Indian Ocean the northeast trade winds blow. The movements of the air about a high are the reverse of those about a low; and, appropriate to each hemisphere, the following laws apply:

1. Cyclonic winds move obliquely in toward the center of a low, spiraling about the center in a counterclockwise direction in the Northern Hemisphere and clockwise in the Southern. They diverge or move spirally out from a high, turning clockwise in the Northern Hemisphere and counterclockwise in the Southern.

2. Although highs and lows sometimes remain stationary or even retrograde, in our hemisphere they usually travel from a westerly quarter, passing off to the northeast, slightly poleward. Separate and distinct from the circulation of winds around the centers of low and high pressure, the whole system of winds has an average translatory movement of over 500 miles a day in summer and over 700 in winter. The average speed of lows over the North American continent ranges from 477 to 718 miles a day; of highs, from 485 to 594 miles a day—the higher speeds governing in winter and the lower in summer.

3. Over the North American continent the average velocity of motion is thus about 31.7 miles an hour, but the velocities of different highs and lows may vary widely. One may linger over a given area for a day or two, whereas another may rush across the country, covering 1,700 miles in a single day. The velocity in winter is about double that in summer.

4. Both in track followed and in velocity of motion, highs are more erratic than lows. Since some highs remain almost stationary for a day or two, perhaps a week, the average velocity of motion is much less than that of lows.

5. Normally, highs that follow lows bring clearing weather, whereas lows that follow highs cause unsettled weather.

MOTION OF STORMS: In the Southern Hemisphere, where the sun goes from east to west via the north, the rotary motion of storms is opposite to that of the Northern Hemisphere. The progressive motion, however, in each hemisphere is from the Equator toward the pole. All storms have a progressive motion, and in many instances cover an area several hundred miles in diameter. Cyclones, or "lows," breed at some place where two currents of air meet which have considerable difference of temperature or moisture content.

LOWS: Extratropical cyclones, or lows, are storm areas of low barometric pressure with counterclockwise spirally inflowing winds in the Northern Hemisphere. They are governed by a moderate wind velocity and large and well-marked changes in temperature and moisture; and the accompanying cloud area is immense. The entire formation moves with moderate velocity from some westerly to some easterly quarter.

Varying greatly in size and shape and bringing stormy weather in the regions over which they pass, extratropical cyclones often travel from the north Pacific to the north Atlantic Ocean within a week. In the United States a favorable place of origin is the Mississippi Valley just east of the Rocky Mountains. If they do not originate in the United States, they enter from the northwest, west, or south. Those entering north of the middle of the country have a tendency to move toward the south in crossing the Mississippi Valley and recurve toward the northeast. In approaching the Atlantic coast, all lows move toward the northeast and generally leave by the St. Lawrence Valley. Similarly, the eastern coast of the British Isles and northwest Europe come under the influence of an eddy-ridden stream of air which flows in from the Atlantic Ocean from the west or southwest. These lows prevent the winds from blowing perpetually from the southwest. Following them are the fair-weather areas, with winds blowing outwardly.

HIGHS: Anticyclones, or "highs," are exactly the opposite of lows, and usually bring fair, cool, and settled weather. They are of high barometric pressure with clockwise spirally outflowing winds in the Northern Hemisphere and counterclockwise in the Southern. The wind velocity is moderate except in the outer parts; calms are frequent, clouds are few, and precipitation is generally lacking. The formation is larger than that of a low and moves in the same general direction..

Highs enter the United States usually from the extreme northwest or over California. As a rule those entering from the northwest follow one of two paths: they may move eastward and slightly southward along the northern boundary of the United States until the Atlantic coast is reached, where they turn toward the northeast and proceed in the direction of Iceland; or they may move southeast over Kansas and the Gulf states to the Atlantic coast near Florida. Those that enter or spread in from over California usually move southeast, joining the customary track just south of Kansas. After leaving the Atlantic coast near Florida, they continue, in the majority of cases, to move toward the southeast in the general direction of Bermuda. (See Air Mass and Frontal Analysis for the movements of air masses.)

IDEALIZED EXTRATROPICAL CYCLONE: Figure 1 shows the structure and a stage in the development of a cyclone; also a frontal cloud system typical of conditions when the air of the warm section is stable.

The sector of warm air is seen spreading to the center of the cyclone, which moves in the direction of the current in the warm sector. A traveling cyclone often consists of a sector of warm air encircled by colder air, both air masses being separated from each other by a front. That portion of the front where warm air replaces cold air is called the warm front. In the rear, cold air replaces warm air along the cold front.

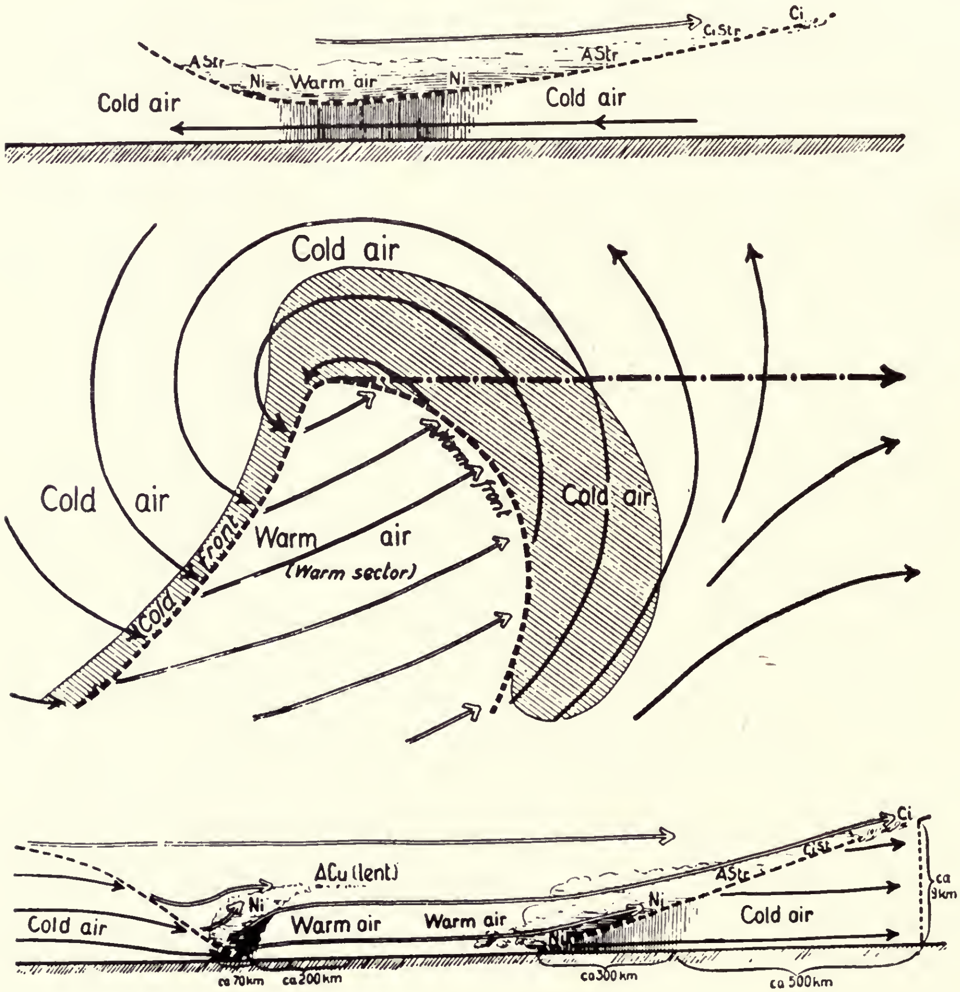


Figure 1.—Idealized Extratropical Cyclone *

* By permission of the United States Weather Bureau.

In the lower portion of the diagram is shown a cross section through the cyclone to the south of the center. Warm air here overruns the wedge of cold air that constitutes the warm-front surface. In the rear of the cold front, cold air cuts under the warm air ahead of it.

Since the warm air is lighter than cold air, it will ascend above the cold air along the frontal surfaces. In the warm sector the air blows up the slope of the warm-front surface. Coming, therefore, under lower pressure, it expands and cools. At this stage the moisture content of the air plays a determining part; for, depending upon the moisture content, at a certain distance above the surface, the warm air will have cooled sufficiently to become saturated with moisture.

Over this level in the warm air above the sloping warm-front surface, a clearly markd system of massive clouds develops. In the sequence to follow, viewed from above and below, clouds will be observed to merge gradually from one type into another.

CLOUD SEQUENCE IN A CYCLONE: At the top of the sloping surface, icy cirrus and cirrostratus will develop, clearly indicating the direction from which they are moving, and thereby the probable center of the cyclone. Since they are not fair-weather cirrus, but of the type that occurs in connection with fronts, they will consist of bands and threads and may merge into cirrostratus or altostratus. Fair-weather cirrus show no association with cirrostratus, and little or no systematic arrangement.

Slowly, cirrostratus will be observed merging into altostratus and, eventually, altostratus, becoming lower and denser, will change into nimbostratus. Certain further characteristics peculiar to the frontal system may be noted. Viewed from below, the arrangement of clouds will present an even appearance entirely different from that of the convectional type. Precipitation is continuous without much, if any, change in intensity. Weak front precipitation may be intermittent.

The towering summit of the warm-frontal cloud system in all probability will consist of ice crystals, and the lower portion of water droplets. In that relatively narrow region occupied by the front—the zone of transition—water gathering on the ice crystals will in time increase their size and weight sufficiently to make them fall from the cloud as precipitation. Cutting under the warm air, the cold air in the rear of the cold front will carry it forward and aloft. Behind the cold front a fairly narrow area of rain may extend forward into the warm sector.

The upper section of the cold-front surface may remain cloudless. Due to the current above the cold-front wedge, the entire cold-front cloud system is likely to be pushed forward. Nevertheless, condensation of water vapor and precipitation will develop in the same manner as along the warm front.

FOEHN WIND: The foehn is composed of potentially very warm air driven over a ridge by the general distribution of pressure and carried down to the valleys on the other side. Consequently, it is warm and dry when it reaches the valley bottom. It is a dry wind with a strong downward component, warm for the season, characteristic of many mountainous regions. The American chinook of the prairies has the same characteristics as the Alpine foehn; it is a warm dry wind coming over the divide of the Rocky Mountains, melting and evaporating the snow in its path. In mountainous regions all over the world, under more than a hundred names, similar breezes blow upvalley by day and downvalley by night. The foehn is distinct from the blizzard winds; the latter are valley winds which come down slopes in consequence of their own gravity.

KATABATIC WIND: The term "katabatic" has come into convenient use in reference to any current of air descending by its own gravity. It is plainly a wind that goes downhill. Such winds are everywhere where there is a relatively cold surface characteristic of glaciers and snow surfaces. Sir Napier Shaw writes:

> The katabatic wind is the more interesting of the convectional winds; it is on the surface and must stay there as long as it possesses a relative coldness, even if it has to travel all the way to the Equator to get properly warm. The foehn wind and foehn clouds belong to the general circulation, and therefore to the distribution of pressure; the katabatic winds belong to no circulation at all—they lose their identity when they come under the influence of the general circulation. Nevertheless, the katabatic wind is an element of more than local interest; it helps at least to supply the stream of cold air that forms what is called the polar front, but might with great propriety be called the glacial front. It is the bitterest enemy of mankind. It causes discontinuity, it maintains the polar (or glacial) front, it supplies the energy that causes the convection, that produces the rain, that accounts for the wind in the cyclonic house of the Northern Hemisphere, that Dove began and Bjerknes has built.*

* *Quarterly Journal of the Royal Meteorological Society*, 53, No. 221 (January 1927), 97. The reference to Dove and Bjerknes is to the fact that the theory of air mass and frontal analysis as developed by Professor V. Bjerknes and his son, J. Bjerknes, Norwegian meteorologists, were first advanced about the middle of the nineteenth century by H. W. Dove, a German meteorologist.

WIND CHANGES IN RELATION TO CLOUD AND WEATHER SEQUENCE: In the Northern Hemisphere the following rules generally apply:

1. A wind from the south and thickening cirrus clouds promise rain to come.

2. A cloudy condition with a wind from the east indicates that the storm is to the south; a west wind, that it is to the north.

3. If the upper clouds are traveling fast, the probability of a local thunderstorm is very slight.

4. Lows tend to move toward areas of least wind velocity.

5. Lows tend to grow in intensity—that is, in wind velocity—as they approach bodies of water. Wind velocity is generally proportionate to the barometric gradient.

6. A veering wind indicates fair weather; a backing wind, foul weather.*

7. A backing wind after a storm has passed may indicate more bad weather.

8. A southeast wind is often accompanied by rain.

BUYS BALLOT LAW: In 1857 Professor C. H. D. Buys Ballot, of Utrecht, Holland, enunciated this rule by which a sailor can determine the direction of the center of a storm from his ship:

"Stand with your back to the wind; the center of the hurricane will be to your left and a little ahead, or in other words, if you stand with your back to the wind, the pressure is higher on your right and lower on your left."

GAUGING THE SPEED OF WIND: The direction and velocity of wind may be affected by the nature of the surface—valleys, buildings, and altitude. As may be noted in observing the travel of smoke clouds near the earth's surface, the speed of the wind is much reduced by friction, intermingling of air masses, and eddies or eddies in formation. Valleys have a tendency to make the wind blow along their length. Buildings increase wind velocity near them and make the wind gusty. Wind velocity increases markedly with altitude, the increase being fairly rapid in the first hundred feet or two. Higher wind velocities occur during the day than at night. The maximum usually occurs between noon and four o'clock in the afternoon, and the minimum in the early morning just before sunrise.

* A veering wind is a wind that moves from left to right—that is, clockwise. If the wind shifts the opposite way, the change is called "backing."

INDICATIONS OF APPROACHING WEATHER CHANGES: The following indications of approaching weather changes are afforded by local observations of the wind and the barometer:

1. When the wind sets in from points between south and southeast and the barometer falls steadily, a storm is approaching from the west or northwest, and its center will pass near or to the north of the observer within 12 to 24 hours, with winds shifting to the northwest by way of southwest and west.

2. When the wind sets in from points between east and northeast and the barometer falls steadily, a storm is approaching from the south or southwest, and its center will pass near or to the south of the observer within 12 to 24 hours, with winds shifting to the northwest by way of north.

In both cases the rapidity of the storm's approach and its intensity will be indicated by the rate and amount of fall in the barometer.

By bearing in mind the usual movements of lows and highs and the conditions that accompany them, coming weather changes may be foretold from the weather charts. Of course, the question of topography and the location of land and water areas with regard to the place for which the prediction is made are the most important factors, and the individual of limited experience should not expect to make altogether satisfactory forecasts without taking into consideration these and other important influences.

CLOUDS AS WIND GAUGES: Clouds travel with the air currents and make visible the speed of the wind at a fixed altitude or altitudes. A knowledge of successive changes in cloud types is not only of value in forecasting weather; but, since clouds are indicators of the vapor structure of the atmosphere, wind direction, speed, and turbulence, it is likewise an important aid to the aviator. He must be able to trace the track and velocity of storms and, in the exercise of regard for the safety of passengers, cargo, and plane, determine the intensity of a disturbance and the state of weather ahead. He must learn as much as possible about the weather as it may influence—that is, retard or accelerate—his flights, his gas consumption, his hours aloft, his courses and drift therefrom. Not infrequently his safety depends upon anticipating atmospheric conditions leading to thunderstorms, rain, snow, hail, fog, ice formation on wings, and so on. By knowing with reasonable accuracy variations in the direction and velocity of winds with altitude and their frequency, he may derive the greatest possible advantage from favorable winds. This also represents an appreciable saving in the cost of operation and augments the desirability of aircraft service.

Changes in the kind, amount, and thickness of clouds are valuable indications of coming weather changes. Not only are cloud movements important in weather forecasting, but also as a means of ascertaining the general drift of upper-air currents. These directions may be determined without the use of instruments for clouds near the zenith by holding the head steady close to some tall object such as a tree or the corner of a building and noting the point of the compass from which the cloud moves across the sky within the field of vision. Observation of cloud movements near the horizon is difficult because of errors caused by the effects of perspective.

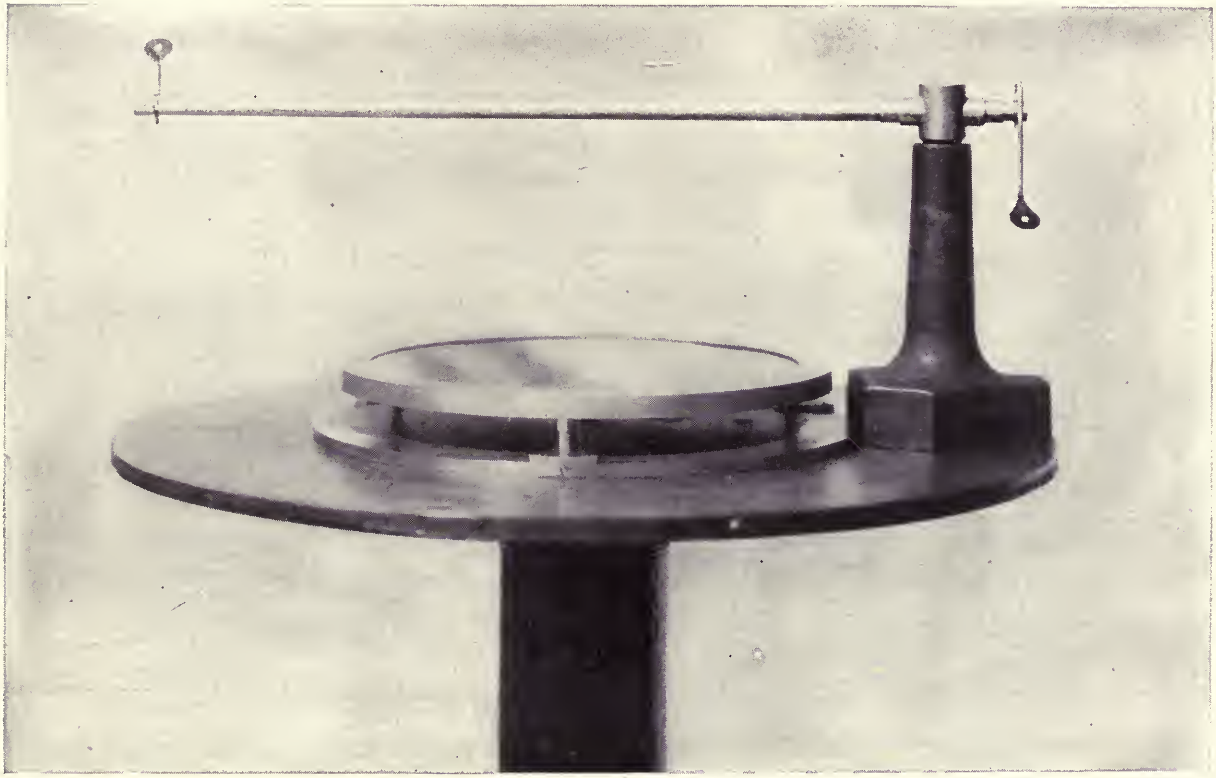


Fig. 2.—The Nephoscope

DIRECTION AND VELOCITY OF CLOUDS: The nephoscope (Figure 2), employed in determining the speed and direction of motion of clouds, consists of a black mirror in a circular frame graduated in degrees, and a movable sighting eyepiece stand. By observing the movement of the image of the cloud, as reflected by the mirror for a certain period of time, the direction in which it is going may be spotted Once the height of the base of the cloud is known, its speed can be determined by timing the movement of the image on the mirror.

The height of the cloud above the earth is ascertained by releasing a standard ceiling balloon and watching it until it disappears into a cloud. These balloons are inflated with hydrogen to a certain pressure, and the observer knows the rate at which it rises. By timing the balloon from the moment he releases it until it enters the cloud, he can make a close estimate of the height of the balloon, and therefore, of the height of the cloud above the surface.

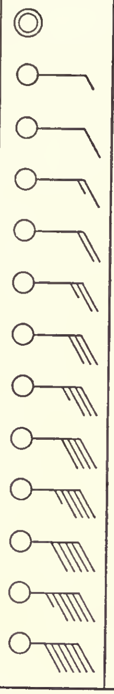
From the two factors described above the observer computes the rate at which the cloud is moving and tells the pilot before he takes off whether he will fly against a head wind or have the advantage of a tail wind.

As regards the types of clouds, and the degree of cloudiness, the observer is obliged to follow the evolution of the clouds since the time of the previous observation and to note the state of the sky as a whole. A single cloud observation is not enough.

THE BEAUFORT SCALE: The Beaufort Scale of Wind Force, devised by Admiral Sir Francis Beaufort in 1805, is a scale by which wind velocities are numbered and characterized by their effect upon various objects. The wind speed as given is for wind at the standard anemometer height of 20 feet above the ground. The significance of such terms as "moderate," "fresh," "strong," etc., in connection with predictions of winds or gales may be understood by reference to the scale. The wind varies from 0, a calm, to 12, a hurricane, rated as the highest force ever attained. The International Radio Weather Code permits the sending of only one digit; consequently, when force is in excess of strong gale, the observer uses code figure 9 and adds the word "gale," "storm," or "hurricane"—as the case may be—to the end of the message. The direction of the wind to be recorded is the true, not the magnetic, direction. Wind direction is more readily ascertained by remembering that the crest lines of the smallest ripples on the sea surface are perpendicular to the direction of the wind.

The number of the feathers on the arrows on weather maps indicates wind force according to the scale. In the wording of all wind forecasts and storm warnings the indicated direction is always the point of the compass from which the wind will blow. Wind speed and velocity vary with the distance above the ground, with the greatest variation near the ground.

BEAUFORT SCALE OF WIND FORCE



NO.	SYMBOL	MILES PER HOUR	*Description*	*Effect upon Common Objects*
0		CALM	Calm	Smoke rises vertically
1		1-3	Light air	Wind direction shown by smoke drift but not by wind vanes
2		4-7	Slight breeze	Wind felt on face; leaves rustle
3		8-12	Gentle breeze	Leaves and small twigs in constant motion; wind extends light flag
4		13-18	Moderate breeze	Raises dust and loose paper; small branches are moved
5		19-24	Fresh breeze	Small trees in leaf begin to sway
6		25-31	Strong breeze	Large branches in motion; whistling in telegraph wires
7		32-38	High wind	Whole trees in motion
8		39-46	Gale	Breaks twigs off trees; generally impedes progress
9		47-54	Strong gale	Slight structural damage occurs; chimney pots removed
10		55-63	Whole gale	Trees uprooted; considerable structural damage
11		64-75	Storm	Very rarely experienced; widespread damage
12		ABOVE 75	Hurricane	

1901 - W.B.

WIND-BAROMETER TABLE: The wind-barometer table, prepared by the United States Weather Bureau, summarizes the wind and barometer indications for the United States with the following explanation:

As a rule, winds from the east quadrants and falling barometer indicate foul weather; and winds shifting to the west quadrants indicate clearing and fair weather. The rapidity of the storm's approach and its intensity are indicated by the rate and the amount in the fall of the barometer.

As low barometer readings usually attend stormy weather, and high barometer readings are generally associated with clearing or fair weather, it follows that falling barometer indicates precipitation and wind, and rising barometer, fair weather or the approach of fair weather. As atmospheric waves or crests (areas of high pressure) and troughs or depressions (areas of low pressure) are, by natural laws, caused to assume circular or oval forms, the wind directions with reference to areas of low pressure are spirally and contraclockwise inward toward the region of lowest atmospheric pressure, as indicated by readings of the barometer. Areas of low barometric pressure are, in fact, whirlwinds of greater or less magnitude and intensity, depending upon the steepness of the barometric gradient. Areas of high barometric pressure, on the contrary, show winds flowing spirally clockwise outward.

The wind directions thus produced give rise to, and are responsible for, all local weather signs. The south winds bring warmth, the north winds cold, the east winds, in the middle latitudes, indicate the approach from the westward of an area of low pressure, or storm area, and the west winds show that the storm area has passed to the eastward. The indications of the barometer generally precede the shifts of the wind. This much is shown by local observations.

During the colder months, when the land temperatures are below the water temperatures of the ocean, precipitation will begin along the seaboards when the wind shifts and blows steadily from the water over the land without regard to the height of the barometer. In such cases the moisture in the warm ocean winds is condensed by the cold of the continental area. During the summer months, on the contrary, the onshore winds are not necessarily rain winds, for the reason that they are cooler than the land surfaces and their capacity for moisture is increased by the warmth that is communicated to them by the land surface. In such cases thunder-storms commonly occur when the ocean winds are intercepted by mountain ranges or peaks. If, however, the easterly winds of summer increase in force, with falling barometer, the approach of an area of low barometric pressure from the west is indicated and rain will follow within a day or two.

From the Mississippi and Missouri Valleys to the Atlantic coast, and on the Pacific coast, rain generally begins on a falling barometer, while in the Rocky Mountain and Plateau districts, and on the eastern Rocky Mountain slope, precipitation seldom begins until the barometer begins to rise, after a fall. This is true as regards the eastern half of the country, however, only during the colder months, and in the presence of general storms that may occur at other seasons. In the warmer months summer showers and thunder-storms usually come about the time the barometer turns from falling to rising. During practically the entire year precipitation on the great western plains and in the mountain regions that lie between the plains and the Pacific coast districts does not begin until the center of the low-barometer area has passed to the eastward or southward and the wind has shifted to the north quadrants, with rising barometer.

WIND-BAROMETER TABLE *

Wind direction	Barometer reduced to sea level	Character of weather indicated
SW. to NW..	30.10 to 30.20 and steady.........	Fair, with slight temperature changes, for 1 to 2 days.
SW. to NW..	30.10 to 30.20 and rising rapidly..	Fair, followed within 2 days by rain.
SW. to NW..	30.20 and above and stationary..	Continued fair, with no decided temperature change.
SW. to NW..	30.20 and above and falling slowly	Slowly rising temperature and fair for 2 days.
S. to SE.....	30.10 to 30.20 and falling slowly..	Rain within 24 hours.
S. to SE.....	30.10 to 30.20 and falling rapidly.	Wind increasing in force, with rain within 12 to 24 hours.
SE. to NE...	30.10 to 30.20 and falling slowly..	Rain in 12 to 18 hours.
SE. to NE...	30.10 to 30.20 and falling rapidly.	Increasing wind, and rain within 12 hours.
E. to NE....	30.10 and above and falling slowly	In summer, with light winds, rain may not fall for several days. In winter, rain within 24 hours.
E. to NE....	30.10 and above and falling rapidly	In summer, rain probable within 12 to 24 hours. In winter, rain or snow, with increasing winds, will often set in when the barometer begins to fall and the wind sets in from the NE.
SE. to NE...	30.00 or below and falling slowly.	Rain will continue 1 to 2 days.
SE. to NE...	30.00 or below and falling rapidly	Rain, with high wind, followed, within 36 hours, by clearing, and in winter by colder.
S. to SW....	30.00 or below and rising slowly..	Clearing within a few hours, and fair for several days.
S. to E......	29.80 or below and falling rapidly	Severe storm imminent, followed, within 24 hours, by clearing, and in winter by colder.
E. to N......	29.80 or below and falling rapidly	Severe northeast gale and heavy precipitation; in winter, heavy snow, followed by a cold wave.
Going to W..	29.80 or below and rising rapidly	Clearing and colder.

STORMS

When currents of air of different temperatures moving in different directions encounter each other on a large scale, storms of rain or snow are generated. Storms vary in their natures according to their immediate causes, some being due to horizontal, and some to ascending, currents of air, modified in their course by chains of mountains and inequalities of surface, or more local causes. In hurricanes the air has a strong rotary

* By permission of the United States Weather Bureau.

motion around a center, which usually remains calm, with a minimum of barometric pressure. All around, the wind blows in various and opposite directions, while at the same time the storm has a progressive motion, its course being marked by the track of its center.

In the language of the meteorologist, there are two kinds of cyclones, "tropical" and "extratropical," often referred to as the "temperate latitude cyclone." The word "cyclone" is of Greek origin and suggests motion in a circle, like a revolving wheel.

Storms of wind which sweep or whirl around a regular course while being carried onward along the earth's surface are: the hurricane, the typhoons of the China Seas, the cyclones of the Bay of Bengal, the ox-eye of the Cape of Good Hope, and the tornadoes of the United States. Like the West Indian hurricane, the typhoon of the China Seas and the cyclone of the Indian Ocean are regularly expected. The tornadoes of the western coast of Africa, the pamperos of South America, and the "Northers" of North America do not possess a revolving motion.

HURRICANES: In the Northern Hemisphere the whirling motion follows the course of east, north, west, and south, to east again; in the Southern Hemisphere it takes the opposite course. In the Atlantic Ocean the region of hurricanes lies to the eastward of the West Indies. They generally traverse the same curved track. It is not often that the lower half of the curve goes as far west as Jamaica or that the upper half swings as far east as Bermuda. Hurricanes are also frequent in the Indian ocean, not far from Madagascar.

West Indian hurricanes originate in tropical regions between the parallels of latitudes 12° and 28°. They first move from east to west, recurve to the northward, and then pursue a northeasterly course. These storms are not of such limited area as the tornado, and they are not nearly as large as the extratropical cyclone. They are characterized by very low barometric pressure and high wind velocities, often in excess of 100 miles an hour. A cyclone originating in the West Indies passing northward into the Temperate Zone is frequently called a West Indian hurricane even after it has assumed the character of an extratropical cyclone. If it is sufficiently severe, it justifies the display of hurricane warnings in United States ports. "Hurricane" is also the designation of the highest wind force on the Beaufort Scale.

One of the first definite signs of a tropical hurricane is the sea swell. As the storm approaches, the sea becomes rougher, and the tide rises above normal. Cirrus or other icy clouds of the upper level, converging at a point on the horizon, also serve as an early warning sign. Some observers consider the point on the horizon at which the clouds converge as a valuable indication of the direction in which the storm center lies. At sunset and sunrise the clouds on the outer border of the hurricane are highly colored; hence a brilliant red sky is one of the well-known signs of an approaching onslaught.*

TORNADOES: The name "tornado" was applied to the thunder squalls of the west coast of Africa long before it was used of local whirlwinds anywhere, and is still used there. In the United States tornado means the destructive "twisters" of the plains states, often popularly called "cyclones." Along the Mississippi Valley and in the Kansas country, "cyclone cellars" are built to provide ports of safe haven. Destructive cyclones are practically unknown east of the Ohio line. Thanks to the bulwark formed by the Alleghenies and the Adirondacks, New York and New England enjoy comparative immunity. Tornadoes frequently sweep down the Tennessee Valley and out through Georgia. Mississippi and other states in the flat country know them well. The following frequency chart shows also the distribution of tornadoes in the United States.

The destructiveness of a tornado is vividly attested to by Will Keller, a Kansas farmer, in this eyewitness account, quoted from the "U. S. Monthly Weather Review":

On the afternoon of June 22, 1928, the air had that peculiar oppressiveness that nearly always precedes a tornado. Between three and four my family and I were out in a field when I saw in the west an umbrella-shaped cloud. Dangling from its greenish-black base like great ropes were *three* tornadoes, the central and largest one perilously near and apparently headed for our place.

We hurried to the cyclone cellar and as I was about to close the door I turned for a last look. While I watched, the lower end of the funnel-shaped cloud, which had been sweeping the ground, began to rise and I knew we were comparatively safe until it dipped again. In a few seconds the great shaggy end of the funnel was directly overhead. There was a strong gassy odor, and I could scarcely breathe.

Looking up, I saw right into the heart of the tornado. The circular opening in the center of the funnel, entirely hollow except for what looked like a detached cloud moving up and down, was 50 to 100 feet in diameter

* For further information on hurricanes, see I. R. Tannehill, "The Hurricane." U. S. Department of Agriculture *Miscellaneous Publications*, No. 97.

TORNADOES *

Number, Deaths, and Damage by States

State or Section	TOTALS 1916-42			AVERAGE YEARLY		
	Number	Deaths	Damage	Number	Deaths	Damage
Alabama	157	640	$11,434,200	5.8	23.7	$ 423,489
Arizona	2	0	2,500	0.1	0	93
Arkansas	272	666	12,312,400	10.1	24.7	456,015
California	14	2	285,500	0.5	0.1	10,574
Colorado	37	27	753,400	1.4	1.0	27,904
Florida	79	23	827,670	2.9	0.9	30,654
Georgia	99	468	24,273,850	3.7	17.3	899,031
Idaho	5	2	29,500	0.2	0.1	1,093
Illinois	124	862	34,467,550	4.6	31.9	1,276,576
Indiana	86	215	14,005,850	3.2	8.0	518,735
Iowa	401	74	13,808,205	14.9	2.7	511,415
Kansas	425	149	14,551,815	15.7	5.5	538,956
Kentucky	28	168	5,202,600	1.0	6.2	192,689
Louisiana	116	230	5,536,220	4.3	8.5	205,045
Maryland & Delaware	40	25	1,670,725	1.5	0.9	61,879
Michigan	72	21	8,813,450	2.7	0.8	326,424
Minnesota	96	146	14,766,300	3.6	5.4	546,900
Mississippi	155	742	11,912,050	5.7	27.5	441,187
Missouri	178	387	34,234,950	6.6	14.3	1,267,961
Montana	45	2	188,525	1.7	0.1	6,982
Nebraska	152	48	5,156,300	5.6	1.8	190,974
Nevada	0	0	0	0	0	0
New England	32	4	1,860,700	1.2	0.2	68,915
New Jersey	11	2	1,560,500	0.4	0.1	57,796
New Mexico	31	5	306,400	1.1	0.2	11,348
New York	20	5	1,237,700	0.7	0.2	45,841
North Carolina	48	39	3,339,300	1.8	1.4	123,678
North Dakota	46	30	1,393,000	1.7	1.1	51,593
Ohio	76	142	18,922,150	2.8	5.3	700,820
Oklahoma	222	404	12,880,567	8.2	15.0	477,058
Oregon	3	0	10,600	0.1	0	393
Pennsylvania	43	10	3,046,500	1.6	0.4	112,833
South Carolina	92	164	7,078,300	3.4	6.1	262,159
South Dakota	101	18	2,241,200	3.7	0.7	83,007
Tennessee	95	264	6,923,800	3.5	9.8	256,437
Texas	359	494	17,562,600	13.3	18.3	650,467
Utah	2	0	4,000	0.1	0	148
Virginia	26	32	1,247,000	1.0	1.2	46,185
Washington	3	0	250	0.1	0	9
West Virginia	2	3	30,000	0.1	0.1	1,111
Wisconsin	109	92	8,076,000	4.0	3.4	299,111
Wyoming	29	3	414,075	1.1	0.1	15,336
United States	3,933	6,608	$302,368,202	145.0	245.0	$11,198,821

* By permission of the United States Weather Bureau.

WINDSTORMS OTHER THAN TORNADOES †

Deaths and Damage by States

State or Section	TOTALS 1916-42		AVERAGE YEARLY	
	Deaths	Damage	Deaths	Damage
Alabama	32	$ 12,321,650	1.2	$ 456,357
Arizona	5	630,355	0.2	23,346
Arkansas	17	2,276,425	0.6	84,312
California	26	7,208,000	1.0	266,963
Colorado	24	1,171,470	0.9	43,388
Florida	2,636	132,013,500	97.6	4,889,389
Georgia	30	2,581,475	1.1	95,610
Idaho	2	49,550	0.1	1,835
Illinois	106	12,742,008	3.9	471,926
Indiana	35	11,374,700	1.3	421,285
Iowa	17	11,007,310	0.6	407,678
Kansas	21	8,453,750	0.8	313,102
Kentucky	60	6,966,200	2.2	258,007
Louisiana	108	23,033,240	4.0	853,083
Maryland-Delaware	38	23,444,875	1.4	868,329
Michigan	188	3,687,260	7.0	136,565
Minnesota	73	12,469,290	2.7	461,826
Mississippi	15	3,750,900	0.6	138,922
Missouri	19	3,940,875	0.7	145,958
Montana	16	902,855	0.6	33,439
Nebraska	12	2,654,600	0.4	98,319
Nevada	0	12,900	0	478
New England	684	307,730,000	25.3	11,397,407
New Jersey	45	6,095,500	1.7	225,759
New Mexico	0	79,150	0	2,931
New York	185	10,897,950	6.9	403,628
North Carolina	24	6,787,800	0.9	251,400
North Dakota	8	2,718,100	0.3	100,670
Ohio	80	6,422,125	3.0	237,856
Oklahoma	37	7,348,650	1.4	272,172
Oregon	10	698,700	0.4	25,878
Pennsylvania	54	5,058,400	2.0	187,348
South Carolina	43	12,048,650	1.6	446,246
South Dakota	26	8,689,225	1.0	321,823
Tennessee	53	2,384,200	2.0	88,304
Texas	466	96,232,675	17.2	3,564,173
Utah	1	1,800,425	*	66,682
Virginia	42	14,627,350	1.6	541,754
Washington	104	4,151,330	3.9	153,753
West Virginia	6	453,500	0.2	16,796
Wisconsin	64	11,864,300	2.4	439,419
Wyoming	1	148,150	*	5,487
United States	5,413	$788,929,368	200.7	$29,219,603

* Less than 0.1.

† By permission of the United States Weather Bureau.

and extended upward for at least half a mile; its walls were of rotating clouds. The whole was made brilliantly visible by constant flashes of lightning which zigzagged from side to side. Around the lower rim of the great vortex small tornadoes were constantly forming and breaking away. They looked like tails as they writhed about, and made hissing and screaming sounds.

I had plenty of time for a good view, as the tornado cloud was not traveling at great speed. It dipped again after it passed my place and demolished the neighboring house and barn, whirling the wreckage round and round in the air. Then it zigzagged away across the country.

Tornadoes develop largely from the thunderstorms of prefrontal line squalls or those of upper cold fronts formed by occlusion processes. They may also develop in connection with cold or warm fronts, near the point of an occlusion, or in the "eye" of a low, the eye being a calm region at the center of a tropical cyclone, or a break in the clouds marking the location of the center.

Although tornadoes have a very small extent, they are more of a problem to a pilot in the air than they are for a fixed location on the surface, because many tornadoes which develop in thunderstorms do not reach the surface.

SIROCCO AND SOLANO: The sirocco of Italy and Sicily, and the Solano of Spain, as also the simoon of Arabia and the harmattan of western Africa, are winds which owe their origin to the heated surfaces of Africa and Arabia. The principal difference between them seems to be that the sirocco and solano acquire more moisture in their passage across the Mediterranean, and therefore do not have the extreme dryness which forms the distinguishing characteristic of the simoon and the harmattan.

THUNDERSTORMS: * Thunderstorms are usually summer and daytime phenomena, although they sometimes occur at night and in the winter. They are much more common in front of lows than behind them. In the United States they occur most frequently in the southeastern quadrant of the low-pressure area. Whereas a general cyclonic storm often lasts for several days and brings rain or snow successively to one part of the country after another in a general sweep, thunderstorms are

* For particularly valuable information on thunderstorms, see "Discussion on Thunderstorm Problems," in *Quarterly Journal of the Royal Meteorological Society,* 67, No. 292 (October 1941), 327-50. In particular, see the paper entitled "The Physics of Lightning," by T. E. Allibone.

brief and local everywhere. As a rule thunderstorms last only about 2 hours and extend over an area of about 20 to 50 miles. They are the product of clouds of the cumulonimbus type when the air is excessively unstable. A more or less continuous line of squalls and thunderstorms, popularly called a "line squall," is common along a well-marked advancing cold front, accompanied by strong, gusty winds, moderate or severe turbulence, and heavy showers. A completely developed thunderstorm brings with it a heavy downpour of rain or hail, and lightning and thunder. Every thunderstorm develops in a field of barometric pressure—along a definite cold front, with a cyclone, or in the neck, or col, between anticyclones.

THEORY OF THUNDERSTORMS: In elementary structure a thunderstorm consists of a core of uprushing air fed by an inrush of air from the front of a storm. The rising air at the center of an active thunderstorm becomes increasingly lighter than the surrounding atmosphere because the heat released by condensation as it is rising keeps it warmer than the air around it. Inertia carries this rising mass far above its equilibrium level, and finally the top of the rising column falls over and pours downward. Cold rain, hail, or snow may assist in cooling the downdrafts, increasing their violence and sometimes resulting in a cold downdraft's reaching the surface. A strong downdraft is usually found immediately behind the updraft, with the air farther to the rear settling down gradually. After a thunderstorm becomes large, there may be a number of different centers of activity.

Factors essential to the formation and development of a thunderstorm are: relatively warm air with sufficient moisture; potentially unstable air—i.e. it must have a vertical temperature and moisture distribution such that if a lower mass is lifted beyond a certain level, it will continue to rise by itself, followed by other air from the surface rushing up the chimney thus made; and, finally, the necessary lifting force must develop to start off the process described above. This trigger action, as it were, may consist of convection currents from a heated surface, upslope winds, the wedge of cold air from an advanced cold front, and so forth.

THUNDER AND LIGHTNING: Thunder may be described as the sound produced by lightning discharge, and lightning as a disruptive electrical discharge in the atmosphere—or, generally, the luminous phenomena attending the discharge. A broad band of nebulous light, unconnected with the occasional streaks of lightning, often extends across the zenith during a thunderstorm.

Thunder is merely the reverberation, or clap, made by a sudden expansion in the air as the bolt of lightning passes through it; it is the sound caused by the violent agitation of the air along the flash. The "rolling" of thunder is due in part to the multiple nature of the lightning discharge, in part to the continuous arrival of the sound from different parts of a long flash, and in part to the multiple echoing from hills and mountains. It cannot be heard more than 25 miles away—usually not more than 10 miles.

Inside the storm cloud itself, air currents ascending at a speed possibly over 24 feet a second, consist of a succession of gusts and lulls. Consequently, the large drops of rain as they fall are split up into smaller drops which then fall less rapidly. Tossed by the rising air currents, drops may rise and fall, grow and break up, over and over again. The shape and structure of hailstones show that high velocities of ascent exist in thunderstorms. Made up of concentric shells of clear ice and snow, they must obviously have been shuttled back and forth between the liquid and the snow parts of the cloud. At high levels the growing hailstone is covered with snow; at lower levels with rain, which changes to ice as the stone is hurled up to colder regions again.

But each time a drop is broken into smaller ones, the negative and positive electricity are separated, the drops taking on a positive charge and the air a negative one. In this fashion, through the continuous breaking-up of water drops, tremendous electric charges are generated and made available for the thunderstorm. The positive charge piles up in that part of the cloud where the ascending current is strongest; the remainder of the cloud is negative or neutral.*

Where, then, does the discharge of lightning originate? There is now reason to believe that all lightning discharges originate within the clouds, either from the positive part of one cloud to its negative part, or from the positive part of one cloud to the negative of another.

Just as the separation of electricity in the lower portions of the cloud is due to the breaking-up of water drops, so in the upper portions it is caused by the rubbing together of snowflakes.

* Measurements of the electric fields of thunderstorms by the High-Voltage Laboratories of the General Electric Company have added greatly to the sum of knowledge on the operation of the thundercloud as an electrical generator. See E. A. Evans and K. B. McEachron, "The Thunderstorm." In *General Electric Review,* September 1936; also McEachron and Patrick, *Playing with Lightning* (New York: Random House), 1940.

Normally air is an almost perfect nonconductor of electricity, but when it is exposed to a very high electrical intensity, its insulating properties break down so that it becomes locally a comparatively good conductor.

PASSAGE OF A THUNDERSTORM: As a thunderstorm advances, the barometer falls and the wind increases, blowing gustily at first in the direction of the approaching storm. When the thundercloud has arrived, the wind changes, blowing away from the storm. At the same time the barometer rises briskly a few millibars. The form of precipitation also changes, the sudden heavy downpour that marked the arrival of the storm giving place to a lighter rain, continuous or sporadic. With a clearing sky the rain gradually decreases in intensity.

Because thunderstorms have a life cycle, their characteristics are considerably different at one time than at another. Observations a few hours old may already be out of date and have little in common with present conditions.

THUNDERSTORM FREQUENCY: Most thunderstorms in our latitudes appear during the period from April to September, with maximum frequency near the middle of the period. Although in the United States three times as many thunderstorms occur over the mountain slopes as in the lower flat areas, the greatest amounts of precipitation associated with thunderstorms have been recorded over the flat areas. Under favorable conditions, thunderstorms develop in groups or families, thus increasing the area subject to rainfall. They travel in the general direction and with the velocity of the wind at about 5,000 feet

Thunderstorm frequency differs greatly in various parts of the world, from an average of 200 per year in some parts of the tropics to almost none in the polar regions, where they occur only at night. Thunderstorms at sea occur more often at night than during the day; on land they are more frequent between noon and 5 or 6 p.m. and least frequent between 3 and 6 a.m. In the southern states, bordering the Gulf, they are mostly of the thermal, or afternoon, type, and rarely occur at night. The thunderstorm period in the United States coincides almost exactly with the summer season.

In the United States thunderstorm frequency varies from about 90 per year in Florida to less than 1 in 2 years in central California. The following table shows the average number of days with thunderstorms at places in the United States.

TABLE OF THUNDERSTORM FREQUENCY

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Average no. per year
	Average no. of days per month with thunderstorms												
Chicago:	*	*	3	3	5	8	7	7	5	2	1	*	41
Cleveland:	*	*	2	3	5	6	7	6	4	2	1	*	38
Detroit:	*	1	2	3	5	7	7	6	4	2	*	*	38
Norfolk:	*	1	1	3	6	8	9	8	3	1	*	*	40
Pittsburgh:	*	1	2	4	6	9	10	8	5	1	*	*	46
Sault Ste. Marie:	*	0	1	1	2	4	4	4	3	2	*	*	21
Washington:	*	1	2	3	5	8	9	7	4	1	*	*	40

SCHEMATIC DIAGRAM OF A TYPICAL THUNDERSTORM: Figure 3 shows in diagrammatic form the important features of a thunderstorm. In the top left of the figure is the strong updraft of air responsible for the development of the storm. Top right shows the cloud formation. Towering, domelike, raised by strong vertical currents of air to a height of 5 or 6 miles, the clouds are accompanied by turbulence which makes their upper portions mushroom out into huge tops which sometimes assume the shape of a gigantic cauliflower as shown top right, or the anvil shown at the bottom. The uprushing blasts of air which shatter the falling raindrops and set up intense electrical fields between different parts of the cloud are shown in the figure at the bottom.

THREE STAGES OF CLOUD DEVELOPMENT IN A THUNDERSTORM: In the top left of Figure 3, the cloud has reached the cumulus congestus stage, with the upward convection current—streamlines of rising air—becoming rapid. At the same time the downward current is comparatively widespread and gentle. At the top right the cloud has grown into a cumulonimbus just before the beginning of rain. The upward current has greatly increased, owing to convection and the release of latent energy; the downward current is still relatively gentle. The figure at the bottom shows the fully grown cumulonimbus incus. Notice the streamlines developed as a result of falling rain. Now both the ascending and descending currents are vigorous. At surface level the descending currents often exceed 60 miles per hour; and ascending currents have been known to sustain hailstones 2 inches or more in diameter.

* Indicates less than 1 day in 2 years' average.

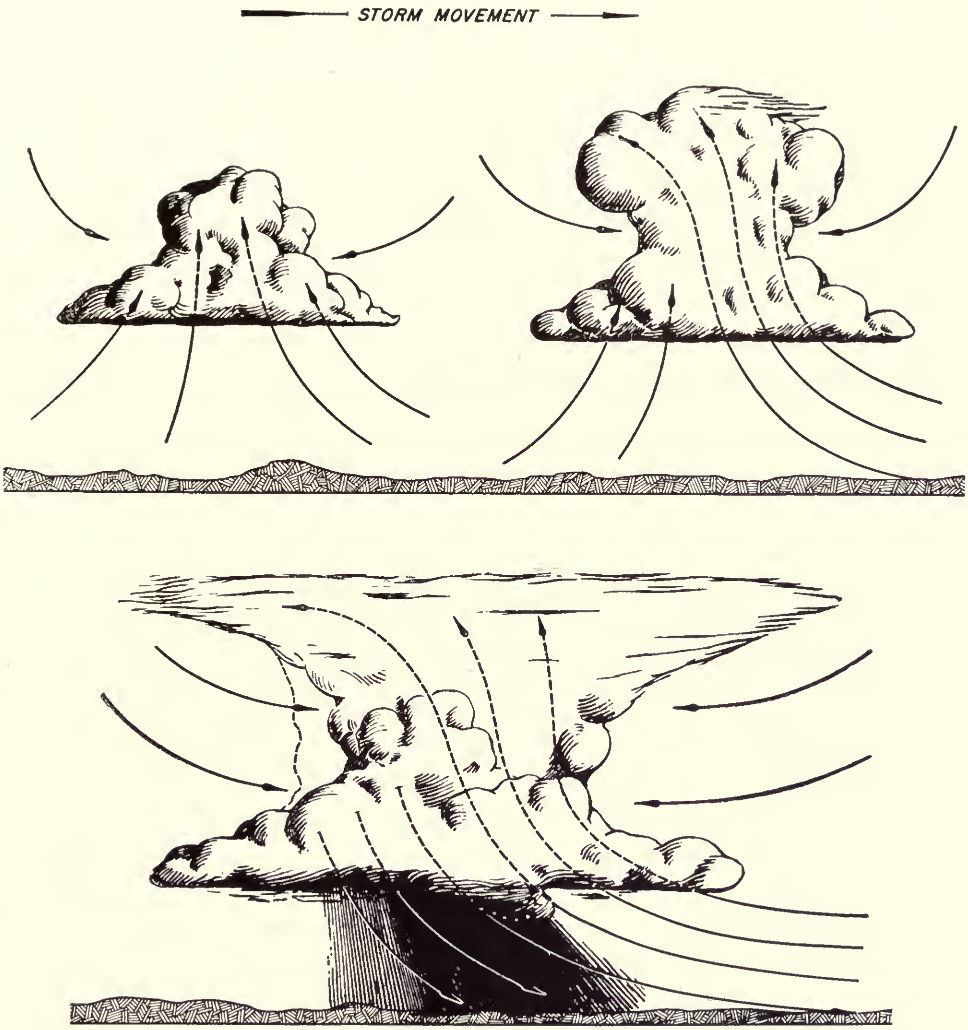


Figure 3.—Schematic Diagram of a Typical Thunderstorm, Showing Three Stages of Development, and Streamlines of Ascending and Descending Air.*

The anvil of the cloud indicates the motion of the air aloft and substantiates the schematic flow patterns shown in Figure 3. It is evident that if a horizontal movement, such as the motion of the storm causes, is superimposed on the vertical motion of the convective currents, the streamlines are essentially as shown in the above figure.†

* By permission of the United States Weather Bureau.

† For detailed study of the subject, consult the following:
Sverre Petterssen, *Weather Analysis and Forecasting* (New York: McGraw-Hill Book Co.), 1940, p. 79; W. J. Humphreys, *Physics of the Air* (New York: McGraw-Hill Book Co.), 3d Ed., 1940, pp. 347-356; and Sir Napier Shaw, *The Physical Processes of the*

HAIL IN THUNDERSTORMS: There is no reliable method of recognizing in advance a thunderstorm which may produce hailstones. For practical purposes, large hailstones occur as often in convection-type storms as in line squalls. They would seem to fall more frequently when the base of the convectively or conditionally unstable region is below 7,000 feet. In order for air-mass storms to produce hail, it appears that the moist air layer should be at least 15,000 feet deep. Hail sometimes occurs within only a small column of a storm. On numerous occasions it has been reported in the clear air closely in advance of thunderstorms, evidently thrown out immediately in front of the storm at a high altitude.

ATMOSPHERICS: These disturbing effects produced in radio-receiving apparatus are found by wireless-direction observations to be emitted from well-defined areas of the globe. A typical area is one in which lightning is being generated in a storm. Such an area has been estimated at about 4,000 square miles in extent, equivalent to a circle 70 miles in diameter. Dr. C. E P. Brooks prepared a map of the thunderstorm areas of the world, with radial lines showing the direction of regular sources of atmospherics.* According to his findings, in south central Africa, the East Indies, Mexico, and Central and South America, there are tropical areas in which very active thunderstorms occur regularly. They are also regions from which atmospherics are received at immense distances and with the greatest regularity.

Atmospherics may, however, originate in areas of rain where there are no thunderstorms. Although every single lightning flash sends out a powerful atmospheric, it does not follow that all atmospherics have their source in a lightning flash. A considerable amount of electrical discharge not connected with visible lightning flashes very frequently occurs in a thunderstorm. Such discharges, without much energy and therefore difficult to recognize far from their point of origin, may take place within clouds and rain areas. Atmospherics are not found in dust storms.

RAIN: Condensation on cloud droplets, or their coagulation, cannot account for the formation of rain. Large or medium-sized raindrops are produced by the action of ice crystals falling through a cloud of water particles. Ice crystals may be present in the tops of towering cumu-

Weather, Vol. III of *Manual of Meteorology* (New York: The Macmillan Company), 1930, pp. 382-3; Sir George Simpson, "The Formation of Cloud and Rain," in *Quarterly Journal of the Royal Meteorological Society*, 67, No. 290 (April 1941), 1-99, and "The Electricity of Cloud and Rain," *Ibid.*, 68, No. 293 (January 1942), 1-34; and J. F. Shipley, "Lightning and Its Symbols," *Ibid.*, 67, No. 290 (April 1941), 135-157.

* *Quarterly Journal of the Royal Meteorological Society*, 62, No. 267 (October 1936), 510-1.

lonimbus, even in the tropics, and so explain the formation of large raindrops in thunderstorms. An instance has been reported of rain falling from an altostratus layer at 14,000 feet when the temperature was approximately 0° C.*

The velocity of fall of raindrops depends upon their size. If the drops grow larger than 1/6 inch in diameter, they will fall with a velocity of over 24 feet per second. By such high velocity the drops break up into smaller drops, which then fall less rapidly. The largest raindrops which reach the earth are about 5.5 millimeters in diameter, and the smallest about 0.01 millimeter. Drops of average size are about 4 millimeters.

A GLEAM OF WATERY HUMOR: One Sunday morning a clergyman sent in a report to the British Meteorological Office reporting 6.11 inches of rain that day. No place is safe from calamity, of course; but, bearing in mind that 3 inches of rain is a very heavy day's work for a British storm, the Meteorological Office could not let this pass unchallenged. To their questions the embarrassed clergyman replied that in place of the rainfall, which was nil, he had copied in the figures of the morning offertory, which was 6 s. 11 d.†

One-tenth of an inch of rain on an acre of ground weighs ten tons. The British Isles, consequently, with about 75 million acres, "impart from overseas" 750 millions of tons of pure distilled water in one day—the equivalent of more than all the shipping that enters the ports of the Isles in several years. ‡

HOW RAIN IS PRODUCED: Rain, no matter how produced, be it land, storm, or thunderstorm variety, comes out of the rising and cooling of warm, moist air. With the exception of very slight drizzle, rain cannot fall without an upward current of air. The actual ascent of air depends upon several factors. The shimmer on surfaces heated by the sun on a hot day is a visible sign of the ascent of warm air.

Assuming the air to be perfectly dry, as it rises it will be cooled at the dry adiabatic lapse rate of 1° F. for every 188 feet. Since the temperature of air diminishes as we go up, a mass of rising warm air is cooling as

* G. S. P. Heywood, "Rain Formation in the Tropics." In *Quarterly Journal of the Royal Meteorological Society,* 66, No. 283 (January 1940), 46.

† The term "1 inch of rain" means that if the total amount of rain falling over a given period were collected and poured out evenly, it would form a layer 1 inch deep. Similarly, "annual rainfall" so many inches signifies the depth of water there would be if all the rain that fell in the year were collected and poured out, none being lost through evaporation or absorption into the soil.

‡ Hugh Robert Mill, *Quarterly Journal of the Royal Meteorological Society,* 53, No. 221 (January 1927), 86-7.

it rises, and at the same time it is getting into increasingly cool surroundings.

On this basis, if a mass of air at a temperature of 70° rose 1,880 feet, its temperature would be reduced to 60°; if the temperature of the surrounding air at this level were below 60°, the rising air would go still higher; if it were 60°, the air would then stop rising because if it went higher, it would be cooler and heavier than the air surrounding it.

But this is not the way it happens; for another important factor enters into it—the process of condensation constantly going on in the atmosphere. Condensing water vapor gives up heat to the air, so that in a rising mass of air two processes are going on: the air is being cooled by expansion, and at the same time warmed by condensing water vapor. On the balance, it is still being cooled, but more slowly than if condensation were not going on.

Moist air will therefore tend to go higher than dry air; but in either case the height to which it will go depends upon the rate at which temperature declines with height in the free air. In fine weather temperature aloft falls off slowly. There are occasions when at 5,000 feet the temperature is only slightly lower than on the ground. In such a case a mass of air which started to rise would very soon be stopped by having its temperature reduced below that of the surrounding air, and we should have clear skies or small clouds marking the limit to which ascending currents could reach.

On the other hand, if the temperature aloft falls off quickly, the rising air, though cooling at the time, may remain warmer than its surroundings up to very great heights. As it ascends, the water vapor continues to condense into drops which coalesce and ultimately form raindrops.

On two different days we may have air containing the same amount of moisture near the surface at the same temperature; on one day it will be fine because the temperature aloft is comparatively warm; on the other we may have rain because the temperature aloft is cool enough to allow the rising currents to penetrate into the upper layers.

The belt of heaviest rain accompanying a storm runs parallel to the path and at some distance to the left. In a land storm, rain falls most copiously where the wedgelike action of sloping land forces the air to rise highest. On meeting the first slope of the hills it rises, and continues to ascend faster and higher as it is driven against the mountains. The rising air cools, and as it cools the water vapor condenses and falls as rain.

LAND RAIN: Land rain is usually light and occurs in quiet weather. Over the mountaintops heavy clouds darken the sky. Not only hills but a coastline will deflect upward a current of air blowing against it, which is the reason why a line of cloud often forms along the coast.

STORM RAIN: In the case of storm rain, the wedge which lifts the air is not a solid land slope, but a moving mass of cold air forced by the surface wind below the warm moist air which it carries into the cold upper region whence the rain descends. Although as a rule its duration is shorter, such rain may last some 24 hours at a single place and may affect a wide area, or produce serious and widespread floods. At the center of activity of the storm's force, the biggest rainfalls on record have been measured. To mention only two: On August 25-6, 1912, at Norfolk, England, a storm passing northward through the North Sea yielded more than 2 inches of rain over 6,000 square miles, 8 inches falling in 24 hours in the wettest spot. On June 28, 1917, at Bruton, England, a storm passing eastward along the English Channel resulted in a downpour of over 9 inches in the one day.

Local thunderstorms that last only a few minutes may discharge some 300,000 tons of water on the earth. Destructive widespread floods are usually caused by too many rainstorms passing over an area in succession. Such was the case in the Mississippi floods in 1927 when the river burst its levees. The heaviest rainfall on earth was 45.99 inches in 24 hours at Baguio, Luzon, Philippine Islands, on July 14-5, 1911. On June 12, 1876, the second heaviest rain on record fell. It registered at Chirapunji, India, over 40 inches in 24 hours. The Western Ghats, along the Bombay coast, show the influence of mountains, the heaviest rainfall occurring in the Khasia Hills, which offer an abrupt wall some 4,000 feet high. Chirapunji at the edge of these hills has a rainfall averaging 500 inches a year, half of which falls in two months. While the tableland of Deccan suffers from drought, Mohableshwar receives about 250 inches. The eastern coast of Australia has an annual rainfall of 160 inches, but on the south it rarely exceeds 25 inches. South African rainfall varies from 22 to 41 inches. Due to the southeast winds which blow from November to February, the east coast of South Africa enjoys the heaviest and most regular rainfall. Japan, taking the average of her nine principal meteorological stations, has a little over 60 inches yearly.

The heaviest rainfall in the United States was 23.22 inches in one day at Smyrna Beach, Florida, on October 10-1, 1924; the heaviest snowfall on one day was 60 inches at Giant Forest, California, on January 19,

1933. In several places in the Rocky Mountains, the mean annual snowfall exceeds 400 inches. For the United States as a whole, snowfall averages 28 inches per winter.* Over the world as a whole, it has been estimated, rain or snow is always falling at the rate of 16 million tons per second.†

Altogether no place is drier by day than northern Africa where the relative humidity descends to 10.25 per cent. However, in that latitude the temperature may drop below 0° C., the abrupt decline being accompanied by the deposition of a rich dew, the sole atmospheric source of water during the long dry season. Although by day the air temperature may exceed 50° C., even then the atmosphere is not nearly as hot as the desert sand. Soil temperatures as high as 85° C. have been recorded in that hatchery of sandstorms—storms which, as the war has demonstrated, are about as severe in fury and duration as any that occur.

THUNDER RAIN: On a warm summer afternoon when a typical thunderstorm straight overhead is in action, a heavy deluge of rain is to be expected. In a single hour during a severe thunderstorm in the Thames Valley, England, as much as 3½ inches of rain or melted hail has been known to fall at a spot. Such storms, however, are rare.

Although it owes its origin to the uprising of warm moist air, the peculiar ferocity of the downpour, as it falls with a noise that almost drowns out the thunder, comes from the exceptional force of the uplift. That in turn may be due to local heating.

To some extent the height to which air is forced upward inside a thunderstorm is indicated by the size of the hailstones, which can be formed only in the intense cold of the upper regions of the atmosphere.

Thunder rain in summer as it comes crashing down bears no relation to the paths of cyclones, nor to the contours of land. After the storm has passed, one may see parallel bands a considerable distance apart of alternately wet and dry patches. Less than a thousand yards may divide a spot without visible signs of rain from one where an inch or more has fallen. In the widest sense, it is the diversity and uncertainty of the distribution of rain in space and time that makes mankind its debtor—rain that cools, cleanses, and purifies the air; that sluices down dusty streets and makes them glisten in the evening light; that revives the drooping flowers of a hundred thousand city window boxes.

* S. S. Visher, "Precipitation Effectiveness in the United States," *Quarterly Journal of the Royal Meteorological Society* for July, 1943 No. 301, pp. 221-7.

† B. A. Keen, "What Happens to the Rain?" *Quarterly Journal of the Royal Meteorological Society,* 65, No. 280 (April 1939), 123-37.

A moist wind off the Atlantic, impinging on the slopes of the Catskill Mountains, precipitates rain on all or part of New York City's hundreds of square miles of watershed. The sky of prosperity over the city is bright because of the Catskills.

A storm bringing rain enough to swell the mountain brooks is most useful; for man now realizes that water, like grain and vegetables, comes in crops, and in seasons of abundance must be stored away to provide for periods of drought.

The only reference made by Shakespeare to the western world is, oddly enough, associated with rain. In some manner unknown to commentators, he heard of the Bermudas; and in "The Tempest" the clown, gazing at a cumulonimbus cloud, speaks of it with fear and trembling: "Foul bombard . . . yonder same cloud cannot choose but fall by pailfuls."

CLOUDBURSTS: Local thunderstorms lasting only a few minutes may dump 300,000 tons of water on the earth, a weight which would shatter the strongest skyscraper if it were released in one chunk. The name "cloudburst" was given years ago to torrential downpours of rain when their cause was not fully known Most of them are caused by violent uprushes of air at the beginning of the storm, carrying the drops up instead of permitting them to fall; when they do fall, a great quantity of water comes down at once.

Cloudbursts are, then, excessively heavy local downpours of rain, but they are of brief duration. In their intensity they bear much the same relation to a widespread heavy rainstorm as a tornado to an ordinary cyclone. Moreover, as violent uprushing currents of air always occur at the front of an advancing thunderstorm—the upward blast being so strong that, for a time, the water is prevented from falling as rain—the majority of cloudbursts are now believed to be the product of violent thunderstorms. The special frequency of cloudbursts in mountainous regions may be due to the weakening of the rising current at some point, permitting a large accumulation of water to fall at once. This happens when a traveling thunderstorm, fed by rising streams of air from overheated ground, passes over the cooler surface of a mountain, so that its supply of warm air is temporarily cut off.

WATERSPOUTS: A waterspout is a slender funnel-shaped cloud extending from the underside of an ordinary cumulus cloud to a mass of spray torn up by whirling winds from the surface of a lake or ocean. Like tornadoes, waterspouts occur with an approaching cold front and a considerable amount of precipitation—usually a deluge of rain. Sometimes a brilliant display of lightning occurs with the accompanying cumulonimbus cloud. When a strong or tornadolike vortex occurs over water, the result is a waterspout. If it touches the ocean, the accompanying cloud column, like the funnel of a tornado, has a low-pressure core capable of lifting water to a height of 7 or 8 feet.

As the spout whirls, it creates a reduced pressure within itself. Expansion of vapor within follows. As sufficient expansion is always accompanied by cooling, the vapor condenses into drops; the quantity of water contained in a spout depends upon the amount of vapor condensed. The spout is made up of water vapor, like any cloud, and a little sea or lake water. Generally the top of a spout moves faster than the base. In the tropics a spout may be developed upward from the sea.

The name waterspout was formerly often applied to a cloudburst even when it occurred far from any body of water

Thousands of waterspouts are formed and destroyed each year. They come usually in groups. Nine times out of ten, the vortex dies almost as soon as it is formed.

The first waterspout officially recorded in New York Harbor was on September 5, 1924. It followed a vicious thunderstorm, the spout twisting out of the upper bay near the south end of Governors Island. It swept along the shore about 200 feet from the seawall. When it reached the northerly point of the island, it rose to a height of 50 feet or more and then collapsed.

A 2,000-foot waterspout, the second and largest one ever recorded in the Port of New York area, occurred early in the afternoon of July 20, 1936. It was observed in the upper bay about 500 yards off Stapleton, Staten Island. It followed a thunderstorm which swept the metropolitan area between 2 and 3 p.m. that day. In a sultry atmosphere the water over an area of about 50 square feet began to churn and bubble as if a boat had foundered. Out of the sky a great black cloud appeared over the boiling water, and simultaneously a swirling, weaving column sped upward. The sky was overcast with a dense formation like a sheet of nimbostratus. The wind was about 15 mph (Force 2). The barometer read 29.28 and the thermometer 78° F. The sea was calm except for the small area where it bubbled and boiled, growing more agitated all the time. Then suddenly it seemed that the sea began rising spirally. It gained speed very rapidly for a few minutes. Meanwhile the cloud began to drop slowly until it looked like a huge pear or inkdrop as it joined the water. For several minutes it appeared to remain in a stationary position, although it was weaving or swaying somewhat. After reaching the full height of what observers estimated to be 2,000 feet, it commenced to move at a moderate speed in a northeasterly direction. The spout was as dark as the cloud. It disappeared suddenly; there was no great splash of water—it simply was gone as though blown away. During the 3 minutes it lasted it whisked away part of a bargeload of lumber being towed to Brooklyn. No one aboard the barge was injured.

In 1932, between 10 o'clock and 10:15 one midweek morning, as many as seven waterspouts were seen at the same time off the coast of Cornwall, England. The cloud was of cumulonimbus type accompanied by heavy rain. The hollow core and the turbulent motion were clearly visible in the cloud, and below each spout was a disturbed patch of sea. The sea appeared to be boiling and had above it white "steam" which was circling rapidly. The funnel did not extend far down on the surface of the water. The barometer was falling, the wind was light and changed with the passage of the cloud from northeast to south.

CHARACTERISTICS OF WATERSPOUTS: 1. The usual diameter of a water spout is from 20 to 60 or more feet; the average height about 1,000 feet. Some few spouts have been found to extend up to a mile from sea level and to measure anywhere from 100 to 400 feet in diameter at the base.

2. Though the waterspout occurs over the ocean, the water in the column is largely condensed from the atmosphere, and is therefore fresh water.

3. Waterspouts last for about 10 minutes and do little damage.

4. They occur in the north Atlantic and north Pacific oceans—off the east coast of the United States and off the coasts of Japan and China.

5. Similarity with the conditions of pressure and temperature peculiar to tornadoes is marked. Sometimes a single towering cumulus precedes the tornado; or again, as in the case of the waterspout, a heavy cumulonimbus, often showing a mammato surface underneath.

DUST STORMS: Increasingly frequent storms of dust swirling high over desolated regions stripped of vegetation and topsoil by drought and erosion, periodically threaten life and property, shut out much of the health-giving radiation of the sun, and denude the land of its growing capacity.

In the structure of the atmosphere, the convection layer—characterized by dust uplifted from near the surface by warm ascending currents—is dustiest and deepest over arid regions and during summer droughts. As temperature increases, the last traces of moisture are removed from the dust, so that it rises more easily.

By analyzing dust, especially against a background of snow, it is possible to determine the region of origin. Thus dust which discolored New England snow showed the proportion of lime that distinguishes southwestern soils. In a dust shower which fell one February on Vermont and New Hampshire, brown dust was found to originate in Texas, Oklahoma, or Kansas, states some 1,500 miles away. United States Weather Bureau observers estimated that this particular winter dust storm deposited 31 pounds of dust per acre, or 10 tons per square mile, in the area where the snow fell. Every 10 tons of dust was estimated to include 1,080 pounds of lime.

Drought in the Balkan States has brought about vast dislocations of soil; dust storms in Australia have peppered the fertile farm lands of New Zealand; ships sailing in the Yellow Sea have collected dust from the Gobi Desert in Mongolia; while across the Mediterranean has come sand from the great Sahara to alight on vessels sailing between Gibraltar and the Azores. The "Sea of Darkness" which terrified early voyagers off the Canaries is only a local condition of poor visibility due to dust blown from the shimmering sands of the Sahara. In reality the mysterious spectacle was an unusual effect of mirage. Red rain mystified the residents of the Italian Riviera one day in March and caused foreboding among the superstitious peasants. The phenomenon was the result of red dust borne from the African desert by steady south winds. The raindrops were colored as they fell through the dust.

In the Western Desert, some 30 miles west of Alexandria, Egypt, the increasing frequency of dust storms began in 1941, 50 being recorded as against 8 the year before. The most severe storm lasted 3 hours in a violent wind, rising to full gale, 50 miles an hour; and at the height of the storm the sun was totally blacked out. To be clear of the dust, a pilot had to fly at 15,000 feet; the main dust cloud reached 12,000 feet. The dust drove across the Mediterranean, leaving its traces on distant warships. In the Libyan Desert, dust clouds rise to an incredible height, smothering everything in their path, a blinding, suffocating fog which at its best may rise to half a mile, and at its worst renders visibility nil.

The most severe drought region in the United States covers North and South Dakota, eastern Montana, western Wyoming, and parts of Minnesota—in other words, the middle and northern grain belt. Within this zone the normal movement of highs and lows is frequently interrupted by a persistent stagnant state of the atmosphere, where every cloud becomes a rainbow and every drizzle is greeted as a guarantee against dust storms. Then in the wake of rain months overdue comes water erosion.

An infliction of Nature normally endured in the western central United States is the "heat wave" each summer. Like the sirocco, it is commonly dry and dust-laden. Continuing sometimes for days, it blows from the west or southwest and withers all growing vegetation Drought is a prolonged accentuation of this heat-wave condition, lasting on and on without rain. To the hot sun that snatches away the water, there is no answer. The more arid the Great Plains become, the greater the possibility of drought, and the more frequent and deadly the onslaughts of dust storms. Where these storms reach their greatest intensity, they have removed the soil of plowed fields to the depth of a foot or more, and have blown seeds and young plants out of the ground. Moreover, as dust particles are charged with static electricity and affect the circuits, long-distance telephone conversations become faint; barbed-wire fences become charged with electricity; mills close because dust is mingling with the flour. Only a few of the more violent storms, however, reach the Atlantic seaboard. By violent is meant that there may be 126,000 tons of earth in a cubic mile of air. The effect of the dust plague is cumulative—once the soil begins to be stripped by the wind, it takes wing at an increasingly rapid rate.

In the United States the wind-erosion area lies between the 100th meridian and the foothills of the Rockies. Blowing steadily eastward from and over this area in line with the center of the storm, and in the path, as it happens, of millions of human beings, a dingy canopy of dust may stretch 3 miles high, travel 3,000 miles, or vault over several countries, to descend again beyond.

Occasionally, supported by a strong upcurrent, soil stripped from the parched earth may hang like a curtain of sand suspended menacingly in midair. Being sharply marked, the upper boundary of the dust layer—including that of the city pall of soot and dirt averaging, in the case of Chicago, some 4 tons a day per square mile—is often clearly visible from any higher level. Should the upper air current be sufficiently strong—and wind uplifting soil is as great a factor in land erosion as water—dust clouds may be driven horizontally as well as vertically with the force of a blizzard.

Photo by Ebro Observatory, Spain; Courtesy, U. S. Weather Bureau

TYPICAL SKY PRECEDING RAIN. Cirrostratus and altostratus with cirrocumulus and altostratus tops, here seen at close range, are characteristic of overflow from intense cyclones. The mixture of clouds illuminated by the sun shows whirling altostratus and combinations of cirrus in an area of marked turbulence. The shadowy parts are altostratus, and the larger rounded tops, altocumulus. Early precipitation is probable in the form of rain, snow, or sleet. Not infrequently an area becomes wrapped in drizzle under a morose pall of cloud—the fine drizzle peculiar to stratus.

Of various deposits of atmospheric moisture, rain is the most frequent, widespread, and copious. Hail occurs almost exclusively in connection with thunderstorms. Showers occur typically in air masses which have a high degree of instability. Snow falls either in separate flakes or in clusters of flakes. Showers, of short duration but often of considerable intensity, fall in relatively large drops from clouds separated from one another by clear spaces. Raindrops may be small and sparse, or large and close together.

Official Photograph, U. S. Army Air Forces

A DAY OF RAIN OR THREATENED RAIN. Heavy cumulus and cumulonimbus, the final phase of cumulus, with stratocumulus below. A cloud curtain falls between earth and sky, blotting out distant views. The air grows humid. Thunderstorms flourish in an atmosphere of high humidity, high temperature, and very little movement of air. With all rapidly developing and towering cumulus, lightning occurs. An electrical discharge in the atmosphere, it is normally associated with cumulonimbus. Indeed, there are few exceptions to the conclusion that cumulus whose summits glaciate emit lightning discharges. In many storms the discharge center is relatively limited in dimensions. When it is so limited in comparison with its height above the ground, the electrical field will be much more intense near the cloud than close to the earth. As the front of the rain area and the lightning discharge center arrive overhead, there is a heavy downpour, with the most severe lightning of the storm.

From Potsdam Meteorological Observatory; Courtesy, U. S. Weather Bureau

PROGRESS OF THUNDERSTORMS (1). This and the three following photographs form a series of thunderstorms in combination. The picture above shows a typical thunderstorm large enough to constitute two storms. The principal cloud mass consists of a combination of several cumulonimbus clouds showing internal motion and turbulence. Cirriform parts of anvils extend to the level of high cirrus. Around the flattened base lies a ragged mass of nimbostratus associated with altostratus immediately above.

Thunderstorms occur when the air is in unstable equilibrium, and their presence indicates that the air is returning to a more stable state. Strong upward currents of air within the cumulus type of cloud—always the main feature of a thunderstorm—are in league with compensating downcurrents inside and outside of the cloud.

From Potsdam Meteorological Observatory; Courtesy, U. S. Weather Bureau

PROGRESS OF THUNDERSTORMS (2). In this second of the series the storms are now in conflict. At the top, right and left, cirrus may be seen detaching itself from the cloud structure. Underneath, formations of clouds in horizontal rolls near and parallel to the horizon are indicative of squalls and the severe storm of thunder and lightning to follow.

In common with squalls, thunderstorms are marked by abrupt variations in temperature, pressure, and wind. They are local disturbances, frequently occurring as episodes in cyclones, and are classified according to the physical factors which presumably cause them. Air-mass thunderstorms from local convection are the most common; frontal thunderstorms, associated with a cold front, are the most intense. Those which occur in thermodynamically cold air masses are classified as orographical thunderstorms.

From Potsdam Meteorological Observatory; Courtesy, U. S. Weather Bureau

PROGRESS OF THUNDERSTORMS (3). This third picture shows the storms breaking up and moving toward the observer. The edges of the anvil are frayed out into cirrus or cirrostratus forms. The major structure of the massive cumulonimbus differs greatly from the rounded cumulus forms below it, and also from the clouds in the picture "Progress of Thunderstorms (1)," showing two pronounced cauliflower domes. A cirrus scarf appears on the left side of the frayed anvil top.

In the lower levels where visible curls are produced, the turbulent cloud takes on the characteristic cauliflower appearance as a result of vortices. On the other hand, when the cloud mass reaches a height where direct condensation from vapor to ice crystal takes place, it presents a fibrous appearance. The reason why the cloud often keeps its cauliflower appearances at distances obviously above ice-crystal level is that it holds water in liquid form at temperatures considerably below freezing.

From Potsdam Meteorological Observatory; Courtesy, U. S. Weather Bureau

PROGRESS OF THUNDERSTORMS (4). The last picture in the series shows the breaking up of the combined storms. The dispersal of the cumulonimbus clouds is accompanied by heavy showers and squalls in a chaotic, thundery sky.

Showers fall when the clouds grow up to their ice-crystal level. Cold-front and thermal thunderstorms have turbulence from the surface to very high levels. In severe storms, vertical velocities exceeding 200 miles an hour may exist. These powerful rising air currents are not dangerous to aircraft in themselves; but when they are associated with downdrafts, very high velocity gradients are created. In heavy thunderstorms such as those shown dispersing in the photograph above, a rapid drop in temperature, possibly as much as 20° in five minutes, occurs in connection with the storm passing overhead or in the immediate vicinity; finally, as the storm passes, wind velocities will exceed 40 miles an hour.

Official Photograph, U. S. Navy

LOOK OUT FOR CLOUDBURST! Typical summer cumulus clouds which may turn quickly into a dramatic thunderhead, distinguished by its dark, flat base. Underneath are fractocumulus and stratus. In such a setting one may expect a sudden and extremely heavy downpour of rain, especially in mountainous regions. In the desert a cloudburst has compensating as well as damaging features. To the Arabs of the Sinai Desert, who never carry an umbrella, a good flood is far the most important event of the year. Each winter, from November to April, it may possibly rain. When it does, suddenly the sky darkens, the wind whips up whirls of dust and sand, and presently a cloudburst turns every ravine into a torrent. In some "rainy" seasons this happens three or four times. Others produce but one brief and useless shower.

Photo by W. A. Wood; Courtesy, U. S. Weather Bureau

A TORNADO APPROACHING. Spinning counterclockwise and associated with large storm systems, tornadoes build up over open prairies and oceans, where they appear as waterspouts. As the tornado progresses, the rapidly whirling funnel bends and writhes. The large end is seen in the tornado cloud above a heavy, low cumulonimbus mass, and the small serpentine end bends toward the ground. The velocity of the winds constituting the whirl may reach 200 or 300 miles an hour.

The accompanying cloud marks the passage of an abrupt cold front of a well-developed cyclone of the V-shaped variety, where winds of different temperatures meet. As a rule, in this section of the cyclone, the surface wind is from the southwest—the reason why most tornadoes move from that direction over the North American Continent. The path of the tornado varies from a few rods to half a mile in width—rarely more. It generally occurs in the southeastern portion of a cyclonic area, where in some cases several separate tornadoes develop simultaneously. They are more common in the plains of North America, east of the Rocky Mountains, than elsewhere. The tornado above was photographed in Nebraska.

Courtesy, U. S. Weather Bureau

TORNADO AT CLOSE RANGE. This photograph, taken at Hardtner, Kansas, on June 2, 1929, shows the violently rotating hollow tapering cloud column extending from the surface, where it is smallest, into the heavy storm clouds overhead. Observe how the dust and debris is being swirled toward the center of the storm due to ascending currents and vortical motions.

Courtesy, U. S. Weather Bureau

WATERSPOUT. This waterspout was photographed from shipdeck on July 21, 1928. A considerable amount of precipitation accompanied its passage, and the air was sultry and oppressive for hours.

Official Photograph, U. S. Navy

AN AERIAL VIEW OF A WATERSPOUT. A waterspout is a traveling spinning cloud, a tornadolike vortex and cloud occurring over water. It is composed largely of water vapor, like any cloud, with the addition of a little sea or lake water. Due to the rapidity of rotation, the cooling responsible for the whirling cloud column is the result of expansion of air incident to the decrease of pressure within the column.

The photograph of the waterspout above, which occurred on June 14, 1929, was taken from an airplane at 500 feet elevation and about 1,500 feet away. The waterspout was ½ mile off Bayou Grande, 2 miles north of the Naval Station at Pensacola, Florida. The column was between 20 and 30 feet in diameter and lasted from 9:31 a.m. to 9:37 a.m. The height of the cloud from which the spout descended was 1,100 feet by altimeter recording.

Photo by Bradshaw; Courtesy, U. S. Weather Bureau

SANDSTORM APPROACHING. Solid earth rises up and joins the wind, blotting out the sun and storming across the land in a conspiracy to numb and obliterate everything in their path. Dust deposited on a given area in a given time varies in different storms and on different surfaces in the same storm. Dust whirls, or "dust devils," begin by the concentrated ascent of highly heated air. The efficiency of any wind in raising dust depends upon temperature, turbulence, moisture, and the available reserves of dust. A velocity of 10 miles per hour sets sand in motion; dust clouds will begin to rise and visibility to fall. Turbulence exists when winds blow from conflicting directions, as when the wind continually veers. Sandstorms sweep over the dusty face of the desert. The photograph above shows a sandstorm at Big Spring, Texas, on September 14, 1930. The upper edge of such a storm, perhaps 2 miles high, is often clearly visible from any higher level.

Courtesy, U. S. Weather Bureau

THE GREAT LEMON CLOUD. This is not a cloud, but a dust storm blotting out the sun as it rides the west wind over eastern South Dakota, April 1934.

Photo by W. J. Humphreys; Courtesy, U. S. Weather Bureau

STORM COLLAR in front of thin dust. Depending upon the velocity of the wind and the dryness of the topsoil, dust storms range from a mere stirring of the dust to the stifling sandstorm.

CHAPTER VI

AIR-MASS AND FRONTAL ANALYSIS

In the study of air masses,* weather is, as it were, the wave action of the air ocean. In discussing air masses the meteorologist uses such technical terms as "polar maritime," "tropical continental," "polar continental," and "tropical maritime" air. In this connection "polar" means "cold" and "tropical" means "warm," classifying the air according to its source region. "Continental" and "maritime," meaning respectively "dry" and "moist," classify the air mass in terms of its moisture content.

When cold polar air and warm tropical air come into conflict, the line of demarcation between them is a "front." One mass of air tries to override the other; sometimes the tropical front advances, and sometimes the polar. Usually a number of polar fronts travel southward and a number of tropical fronts move northward. The object of air-mass analysis is to determine the origin, polar or tropical, of the air masses and to estimate coming weather from their probable behavior at the lines of separation.

WIND-SHIFT LINE: A rapid change of direction in the wind along the line of a cold front is known as the wind-shift line. Often the change is as much as 90° in a minute.

AIR-MASS PROPERTY: In air-mass and frontal analysis, an air-mass "property" signifies any quality or quantity the nature or value of which can be employed in a characterization of the physical state or condition of an air mass. Any air-mass property is regarded as "conservative" if it is affected comparatively little by the various modifying influences to which a moving body of air is exposed. It follows that "representative observations" giving the true or typical meteorological conditions prevailing in an air mass—a widespread body of air which approximates horizontal homogeneity—must be relatively little influenced by local conditions. The properties, level for level, remain almost constant over a wide area.

* *Vide* B. C. Haynes, *Meteorology for Pilots,* U. S. Department of Commerce C. A. A. Bulletin, No. 23. On a synoptic weather map, blue pencil is used for entering air-mass abbreviations for air of polar origin, and red for those of tropical origin. The symbol for superior air (S) is entered in red.

OCCLUDED CYCLONE: Cold and warm air masses—that is to say, cold or warm relative to neighboring air masses—imply that the particular mass originated in a latitude higher or lower than that in which it now exists; and that it is therefore either colder or warmer than the surface over which it is moving. To denote the process whereby the air in the warm section of a cyclone is forced from the surface to higher levels, as when a cold front overtakes a warm front, the term used is "occlusion." The process is accompanied by an increase in the intensity of the cyclone.

Whereas there are several kinds of cyclones, an occluded cyclone thus stands by itself as being one cut off from the parent mass of warm air. The parent air mass is simply a large body of air within which the conditions of temperature and moisture in a horizontal plane are essentially uniform. "Discontinuity" is applied to a zone within which there is a comparatively rapid transition of the elements. A surface of discontinuity between two juxtaposed currents of air possessing different densities—or, more simply, the boundaries between two different air masses—has come to be known as a "front" *

WHAT A FRONT IS: Fronts, cold and warm, are thus the separating plane (sloping) between a cold and a warm air mass. An occluded front is formed when and where the cold front overtakes the warm front of a cyclone. This front marks the position of the surface front. Cold and warm fronts are used to denote the discontinuity at the forward edge of either an advancing cold air mass or an advancing current of relatively warm air which is displacing either warmer air in its path or a retreating colder air mass.

"Polar front" is therefore fittingly applied to the surface of discontinuity separating an air mass of polar from one of tropical origin.

ORIGIN OF STORMS: Most storms originate along a front between pronounced cold and warm air masses. As the front moves, the storm moves with it. A front may extend over many miles.

The theory of air-mass analysis recognizes that the change in temperature between the polar and equatorial regions is by no means perfectly gradual; but that at certain places an abrupt change in tempera-

* On a synoptic weather map, fronts are represented by lines drawn between air masses of different density or temperature. They are called warm fronts when warm air is replacing cold air at the surface; cold fronts when cold air is displacing warm. For surface fronts, heavy solid blue lines for cold fronts, red for warm fronts, and purple for occluded fronts are used; for upper fronts, broken lines in corresponding colors are used. Stationary fronts are shown by continuous single lines composed of alternating red and blue segments. Haynes, *op. cit.*, p. 48.

ture exists. Also, that most of our protracted storms, especially in winter, have their conception in a wave action along a so-called "frontal surface" where a cold air mass meets one that is warmer. Like the tornadoes and other more violent cyclones, these storms are cyclonic.

To the north and south of the dividing line winds blow in opposite directions—from the east in the north and from the west in the south. The lighter warm air blowing east above the heavier, colder air blowing west, sets up waves along the frontal surface. Underneath the warmer air of the south the cold air of the north spreads out in a thin wedge. The frontal surface dividing two air masses differing in density and temperature, becomes the important center of an immense store of potential energy.

The frontal surface, about a mile to a hundred miles long, is much more nearly horizontal than vertical. Should the waves, stretching from crest to crest, exceed 400 miles, they will become characteristically unstable. Ultimately, as they increase in height, they will break up in the same manner as ocean waves on a sloping beach

The cyclone commences when a tongue of warm air first flows north into and above the cold air, then curls back, making an eddy in air of several hundred miles in extent. The energy thus stored along the frontal surface is sufficient to raise the air in the cyclone to colder levels. Should a cyclone lose its energy, and therefore its identity, thus becoming occluded, the energy will be used to form a new cyclone along the frontal surface where the air waves are moving.

Rain or snow come about through the air being lifted and cooled.* There are different processes with correspondingly different results, by which the air is lifted and cooled to the condensing point. For example, in a warm cyclonic air mass, the air climbs up over a very gradual incline of colder air; as a result, the storm gathers slowly, continues longer, and is less violent than in a thunderstorm, for instance, where instead of a gradual incline, there is a vertical lift.

Around the pole the air is very cold. This cold air extends southward in winter over Canada and a considerable portion of the North American Continent. Its progress southward over the oceans is counteracted by the warmth from the water. In particular, over the north Atlantic the Gulf Stream, bearing much heat from the tropics, supplies heat to the polar air thus met.

* See further, Sverre Petterssen, "Condensation Caused by Mixing." In *Quarterly Journal of the Royal Meteorological Society,* 68, No. 295 (April 1942), 167-77.

In winter a great potential front is set up in opposition to the cold mass of the Arctic regions in a gigantic divide from the warmer masses of air to the south. This is the Arctic front in the extreme northern portion of the Pacific Ocean, extending south along the Rocky Mountains. For all practical purposes, this partition may be regarded as a battle zone of the elements—a front along which most of the winter storms that sweep eastward across the continent, partly as a moving air mass and partly as a wave, have their origin.

Sources from which much rain comes to the East and South of the United States are the tropical air masses over the Mexican Gulf and the Atlantic coast east of the Gulf. Over these waters, air that has become very moist flows inland from Texas to the Atlantic coast. Much of the rain that falls east of the Mississippi has its origin in the south Atlantic and the Gulf.

Precipitation and storm follow the pattern of the seasons, so that in summer over the Appalachian Mountains, rain results from air that has made a forced ascent. At this stage the air becomes warm and light, and as a result of further condensation becomes so very unstable that thunderstorms frequently occur. In winter a wedge-shaped mass of polar continental air reaches far south for the season; and the air, warm and moist, is forced to climb over it, with the resultant condition of rain or snow.

APPROACHING COLD FRONT: The dividing line between areas of high and low barometric pressure is not always marked by a change in wind direction and clearing skies; sometimes it is the scene of a line squall along which violent winds and often thunderstorms occur. Occasionally, therefore, line squalls and severe thunderstorms with hail may accompany the passage of a front. After a cold front has passed, there is usually: (1) a rise in atmospheric pressure, (2) a fall in temperature, and (3) a pronounced change in wind direction; and frequently (4) a severe cold wave, and a series of subzero temperatures.

APPROACHING WARM FRONT: The weather conditions usually accompanying the approach of a warm front are: (1) increase in temperature, (2) increasing and lowering clouds, and finally, if in winter, rain or snow, and (3) falling pressure; and frequently light to moderate ground fog. After a warm front has passed, the sky is clear with scattered cumulus. The air is slightly bumpy because of rising air currents.

TRANSITION ZONE: The relatively narrow region occupied by a front wherein the meteorological properties show large variations over a short distance and possess values intermediate between those characteristic of the air masses on either side of the zone is identified as a "transition zone." Thus the boundary between the trade-wind systems of the Northern and Southern hemispheres—intertropical front—manifests itself as a fairly broad zone of transition commonly known as the doldrums. The intertropical front does not affect the United States.

PRECIPITATION: The precipitation of moisture, either rain or snow, from the atmosphere depends upon the expansion and consequent cooling of a body of moist air, subject to the condition that no heat reaches it from the outside during the process. This condition is always nearly satisfied in the movements of large masses of air.*

BERGERON CLASSIFICATION: Bergeron, the Norwegian meteorologist, distinguishes between air which is colder than the surface over which it is moving—cold air mass—and air which is warmer than the surface over which is is moving—warm air mass. This classification indicates whether the air is of Arctic, polar, tropical, or equatorial origin; also, whether the air gained its properties over a maritime surface or a continental surface. Modifying influences tend to alter the structure and properties of the polar and Arctic air as it moves southward—namely, supply of heat and moisture from the surface of the earth; subsidence and turbulence caused by powerful winds over a rough surface.

SOURCE REGIONS: The Bergeron classification implies the existence of the Arctic front between Arctic and polar air, and the polar front separating polar from tropical air. The source region for Arctic and polar air masses comprises most of the continent of North America above the 15 parallel from Hudson Bay to Alaska and northward into the adjacent Arctic regions. Mountain ranges paralleling the Pacific coast and surrounding the Gulf of Alaska help to shut out the invasion of warm air from the Pacific.

Relatively cold air from the north Atlantic moves into this region. As, in winter, the air spreads northward over snow-covered areas, it is rapidly changed into a mass which is very stable in the lower levels. Condensation caused by this intense surface cooling decreases visibly. A good example lies along the central and north Atlantic coast, following a sluggish movement of air northward over the cold waters of the Labra-

* In a synoptic weather map a well-defined area of precipitation is indicated in the following ways for different kinds of precipitation distributed over the area:

Continuous shading for an area of continuous precipitation.
Hatching for an area with intermediate precipitation.
Shower signs for an area with showery precipitation.
Drizzle signs for an area with drizzling precipitation.

dor Current. In such instances, deep fogs with very low ceilings and even a light rain or drizzle may develop. Their origin is due to the chilly atmosphere of that region and the comparative warmth of the adjacent ocean, the temperature of which is apparently raised by the waters of the Gulf Stream. Except in certain unusually warm winters, most of the Pacific air masses move eastward across the continent without reaching the surface. Over the Atlantic and Pacific oceans the seasonal migration is not as pronounced as over the continental areas; the strength of the front, however, is often greater.

When an extensive portion of the earth's surface is characterized by uniform surface conditions and is so placed in respect to the general atmospheric circulation that air masses may remain over it long enough to acquire definite characteristic properties, such an area is a "source region." Good source examples are expanses of uniformly warm tropical oceans or ice-covered polar regions. An air mass that originates over an ocean area in the tropics—tropical maritime air—is characterized by high surface temperatures and high specific humidity. As compared with a marine climate, a continental climate, embodying the characteristics of the interior of a continent, enjoys a large annual and daily range of temperature.

Polar maritime air is characterized by moderately low surface temperatures, moderately high surface specific humidity, and a considerable degree of vertical instability. The term is used to describe any air mass that originally came from the polar regions but is now modified by reason of its passage over a relatively warm ocean surface.* Similarly, polar continental air, characterized by low temperatures, low specific humidity, and a high degree of vertical stability, describes any air mass that originates over land or frozen ocean areas in the polar regions.

The effect of the air moving over the land surface in summer is approximately the opposite of that in winter; heating from underneath tends to increase its instability and, under favorable conditions, to produce thunderstorms.

The general circulation of the atmosphere decreases in intensity during the warmer part of the year. As a result, the polar outbreaks are much weaker, and the movements across the United States of polar continental types occur more slowly than in severe winter outbreaks.

* See further, E. W. Hewson, "The Application of Wet-Bulb Potential Temperature to Air Mass Analysis." In *Quarterly Journal of the Royal Meteorological Society,* 63, No. 268 (January 1937), 7-31.

DIVERGENT AND CONVERGENT WINDS: Wind is generally limited to air moving horizontally, or nearly so—moving air, especially a mass of air having a common direction of motion. Vertical streams of air are usually referred to as "currents." All winds near the earth's surface contain eddies—more or less developed vortices in the atmosphere. Eddies at any given place produce gusts and lulls. Air containing numerous eddies is turbulent, in meteorological parlance. Evidence of vertical currents of surprising velocity lies in the ability of a glider or an eagle to remain aloft without support other than the thermal. Currents directed upward sometimes extend to very great heights; in the towering cumulus they may reach above 25,000 feet. Sudden horizontal variations in the wind cause bumpiness, which is also experienced when an aircraft passes a temperature inversion, which latter are usually wind discontinuities.

Areas of divergent winds are regions unfavorable to precipitation. When the distribution of winds within a given area is such that there is a net horizontal flow of air outward from the region, the resulting deficit is compensated by a downward movement of air from above.

FRONTOLYSIS: The term "frontolysis" is used to describe the process which tends to destroy a pre-existing front. It is usually brought about by horizontal mixing and divergence of the air within the frontal zone.

FRONTOGENESIS: This term describes the process which creates a front—i.e. produces a discontinuity in a continuous field of the meteorological elements; also applies to the process which increases the velocity of a pre-existing front. Frontogenesis is generally set up by the horizontal convergence of air currents possessing widely different properties.

CYCLOGENESIS: Similarly, cyclogenesis applies to the process which creates or develops a new cyclone. It is also used for the process which produces intensification of a pre-existing cyclone.

SUBSIDENCE: A slow downward motion of the air over a large area, subsidence, accompanies divergence in the horizontal motion of the lower layers of the atmosphere. On the other hand, stable air, or a state of stability, exists when the vertical distribution of temperature is such that an air particle resists displacement from its plane; and just as areas of divergent winds are regions unfavorable to the occurrence of precipitation, areas of convergent winds are favorable to it, the distribution of winds within the prescribed area being such that there is a net horizontal inflow of air into the area The opposite is also true, the removal of the resulting excess being accomplished by an upward movement of the air.

INSTABILITY: The term "instability" applies to a state in which the vertical distribution of temperature is such that an air particle, if given either an upward or a downward impulse, will tend to move away with increasing speed from its original level.

SUMMARY: Streams of air, flowing from polar and equatorial regions respectively—and therefore differing in origin, temperature, density, moisture, and dust content—may exist side by side with little if any mixture. According to the conception which has come to be known as the "polar front" theory, cyclones, or lows, may form in a more or less wavering line along the boundaries between cold polar air currents and warm currents coming from the equatorial regions.

Whereas in the polar regions air is relatively cold, dry, and free of cloudiness, equatorial air is warm, moist and frequently cloud-laden. Between the opposite moving masses of cold polar and warm tropical air there is no free and continuous interchange. On the contrary, a narrow zone of discontinuity—perhaps 5 or more miles wide—delineates the boundary which separates the two air masses. Along this front, or surface of discontinuity, cyclones form successively and often in families. Each cyclone of a family tends to form and move southward of its predecessor until the series terminates and another commences in higher latitudes. In the words of Sir Napier Shaw, "the barometer loses its position as a soloist, and its place is taken by tropical and polar air, and by their duet the weather of the temperate latitudes of Europe is brought into relation with the general rhythm of the world's weather."

Sudden changes in wind direction and temperature, also definite interactions producing clouds, rain, and other phenomena, usually characterize the front locations where cold air cuts under warm air masses or when warm air meets and rises over cold air masses. Occasionally, however, the transition in weather is not so impressive. The form and intensity of interaction depend on the differences in characteristics of the dissimilar air masses involved, their extent, and the rapidity with which they are brought together.

In the Northern Hemisphere a bend or wave in the line of discontinuity, generally to the southwest of an anticyclone, indicates the beginnings of another cyclone. Owing to the effect of the earth's rotation, cold and relatively dry air, moving from the polar regions toward the Equator, is deflected to the right of its own direction of movement.

Warm, moist air, moving from equatorial regions poleward, is similarly deflected.

Two common instances of cyclones forming thus, in our hemisphere, along the boundary between warm and cold air masses, occur when (1) warm air from the southwest rises over a wedge of cold air, causing extensive cloudiness and precipitation; and (2) cold surface winds from the west and northwest cut under the warm air of tropical origin, resulting in forced ascent and cloudiness, with heavy and usually brief showers. The cold front is, generally, the trough or squall line of the cyclone at the surface.

As a general rule, in middle latitudes the motto applies: "Eastward the course of the weather makes its way." Following the direction of the prevailing winds, weather moves generally from west to east in our latitudes. High-pressure (anticyclonic) areas and cold fronts move toward the southeast; and low-pressure (cyclonic) areas and warm fronts toward the northeast. Beneath the warmer, lighter air of a warm air mass, the dense air of a cold air mass is inclined to spread continually southward and to displace the warmer air currents northward. As a rule, the front between the warm and cold masses is inclined at a small angle to the earth's surface.

Any modification of the source region characteristics of large masses of air traveling long distances over the earth's surface is usually accomplished first at the surface, later aloft. Characteristics peculiar to the source region—whether polar, tropical, continental, or maritime—of any considerable mass of air in motion are not limited to air near the surface, but extend several miles up. Not only so, but in keeping with source characteristics and accentuated by terrain features and the motion of the air, clouds, rain, and other weather effects may occur within air masses where nuclei are normally present. Unstable moist air may need only slight initial lifting to start its own vertical currents.

REFERENCES: The above discussion of air-mass analysis is intended only as a synopsis. For fuller treatments consult the following:

Woolard, Edgar W.: "Physical Interpretation of the Weather," in "Journal of Applied Physics," 9, No. 1 (January 1938).

————; Samuels, L. T., and Stevens, W. R.: "Graphical Thermodynamics of the Free Air," "U. S. Monthly Weather Review," 54 (1926), 454-7.

Haynes, B C.: "Meteorology for Pilots," "Civil Aeronautics Bulletin," No. 25 (January 1942).

Bjerknes, J.: "Investigations of Selected European Cyclones by means of Serial Ascents," "Geofysiske Publikasjoner," II, No. 4 (1935).

"Admiralty Weather Manual," London, 1938. H. M. S. O. for Hydrographic Department, Admiralty, Whitehall, London SW.

CLOUDS PRODUCED BY AIR MASSES

I. Cold air masses produce cumuliform clouds—cumulus and cumulonimbus—the other characteristics peculiar to the air mass being: turbulence in the lower levels; unstable lapse rate (nearly dry adiabatic); good visibility; showers, thunderstorms, hail, sleet, snow flurries.

All towering cumuliform clouds indicate instability.

II. Warm air masses produce stratiform clouds—stratus, stratocumulus, fog or ice-crystal fog—the other characteristics being: smooth air (above surface-friction level); stable lapse rate; poor visibility (smoke and dust held in lower levels); drizzle, dew.

Air-mass fogs are produced chiefly by the cooling of air already moist until a sufficiently high relative humidity is obtained. This cooling may be caused by contact cooling or radiation. As compared with air-mass fog, frontal fogs are usually limited in extent and dependent upon phenomena associated with fronts. Mists and fogs are of more common occurrence in low, damp areas than in dry, elevated zones

In summer, stratus clouds develop along coastal areas. In the event of cyclonic activity, a convergent flow of air along the frontal zone may produce drizzle and low cloud ceilings. In warm air stratiform clouds may form several miles in advance of a surface front.

The stability of the air may be ascertained from soundings or the type of clouds present. Just as stable warm air will produce stratified clouds with continuous precipitation and in the warm air not much turbulence within the cloud, unstable masses give cumuliform clouds. In the latter case, precipitation will be showery, with turbulence within the cloud.

Moist air aloft usually results in cloudy weather; very dry aloft, in clear weather. Again, clouds and precipitation at fronts depend upon the slope of the front—whether flat or steep. Flat fronts produce exclusive cloudy areas with large zones of precipitation. Steep fronts produce narrow bands of cloudy areas with precipitation locally along the immediate front. The underlying factors responsible for the respective fronts are as follows:

Steep fronts—strong wind discontinuity; cold-front type; small difference in temperature; location in a northerly latitude.

Flat fronts—small wind-velocity differences in the two air masses; warm-front type; large temperature difference betwen air masses; location in a low latitude.

Photo by J. C. Hagen; Courtesy, U. S. Weather Bureau

LINE SQUALL. The line-squall cloud precedes a cold front. In this photograph, taken on June 10, 1936, a line of squalls marks the position of an advancing cold front. A line squall is a storm occurring along a protracted front, sometimes extending more than 500 miles. In most low-pressure areas running northeast to southwest, line squalls occur along the line of the cold front. Throughout this line, known as the wind-shift line, the wind changes direction rapidly from southwest to northeast, hence the name. On the approach, therefore, of a line squall—a continuous line of squalls and thunderstorms traveling broadside over the country—one may expect a sudden increase of wind followed by a lull; a sudden rise in temperature; a change in wind direction; and a line of dark clouds precipitating rain, snow, or hail. In extreme cases, waterspouts and tornadoes may occur along the line squall.

Line squalls rarely reach higher than 6,000 feet; usually they are from 5,000 to 6,000 feet; whereas thunderstorms often reach 20,000 feet.

Courtesy, U. S. Weather Bureau

AN APPROACHING WIND STORM. A long line of squall and thunder clouds march ahead of the wind. The lower plane of the clouds is nearly horizontal, and from a tablelike base rise projections the shape of which can be compared to enormous balls of wool more or less carded and connected one with the next. Compared with air-mass cumulus, line-squall clouds do not appear at widely spaced intervals. Rather, they marshal side by side and traverse the full extent of the front. A very intense line squall may register gusts up to 100 miles an hour. The wind squalls accompanying it may be intensely destructive, particularly to lighter-than-air machines.

Courtesy, U. S. Weather Bureau

AN APPROACHING FRONT. An approaching front like the one photographed above heralds discontinuity * at the leading edge of an advancing mass of cold air which is displacing warmer air. Throughout a cold front, as a rule, the contrast in temperature between the two masses of air is greater than along a warm front; moreover, the slope of the discontinuity is steeper. An air mass is cold in relation to adjacent masses of air when it originated in higher latitudes than the one through which it is passing. It is therefore colder than the surface over which it is traveling. Differences in pressure around fronts, cold or warm, and the speed with which this pressure changes, indicate their movement. Thus, a cold front moves faster, the greater the rise in pressure behind it within the preceding 3 hours; a warm front moves faster the greater the fall in pressure in front of it within the same time.

* Discontinuity refers to a zone of comparatively rapid change (p. 146).

Photo by W. Henderson; Courtesy, U. S. Weather Bureau

ENCOUNTER OF AIR CURRENTS ALONG A COLD FRONT. This photograph, taken at Sacramento, California, shows the cloud formation incidental to a cold front along which unstable air moves tempestuously from points southeast. The character of the terrain and the geographical position of a cold front have a much greater bearing on the accompanying clouds than in the case of a warm front.

Photo by W. Henderson; Courtesy, U. S. Weather Bureau

WHEN AIR CURRENTS ALONG A COLD FRONT MINGLE. This menacing forerunner of rain and storm was photographed at Sacramento, California. Unstable air moving from the southeast is being displaced by cooler air arriving from the northwest. The result is turbulence within the clouds, and the outbreak of a storm. The watery sun to the left of the rain screen below the heavy, dark cloud roll indicates turbulence in the air.

Photo by W. Henderson; Courtesy, U. S. Weather Bureau

FRONTAL CLOUD FORMATION. This cloud formation, photographed at Sacramento, California, marks a later stage in the encounter of air currents along a cold front. Since the cloud base now almost overhead was ominously low and the numerous ascending currents of high velocity, lightning was frequent and vivid. Cold-front clouds appear suddenly on the horizon and move rapidly across the sky.

Courtesy, U. S. Weather Bureau

AFTERMATH OF A COLD FRONT. Following the passage of a cold front, lower clouds are clearing, moving to the southeast, banked heavily to the southeast and east. Cirrocumulus is seen in the upper right, center; cirrus at the extreme right; and stratocumulus at the bottom of the picture. Thin altostratus, at the lower right, may also be seen transforming into increasing altocumulus, which merges into dense altostratus at the lower left. Sometimes this combination precedes rain. Upon the passing of a front—and a front is a wind-shift line—the wind increases its speed and changes direction clockwise—from S to SW or from SW to NW, for instance. This change is often abrupt, bringing with it the tell-tale effects, particularly in winter, of a considerable drop in temperature and a picturesque sky. This applies to all fronts, cold, warm, or occluded.

Photo by A. J. Weed; Courtesy, U. S. Weather Bureau

UNUSUALLY LOW THUNDERCLOUDS. Low cumulonimbus in a long belt, or roll, as pictured above, usually marks the front of an advancing wedge of cold air at a moderate elevation over the appreciably warmer air near the surface. Although the clouds may extend thus, chain-fashion, for several hundred miles, the distribution of cold-front thunderstorms is usually limited to a zone some 50 to 60 miles wide. Warm-front thunderstorms, on the contrary, are scattered in the area immediately preceding the warm front. Thunderstorms of this type—towering thunderheads rising out of the undulating summit of an overcast—are known as "high-level thunderstorms." Because of their height, lightning may be seen flashing from one cloud to another and seldom reaches the ground. Here we have cumulonimbus formed in a long belt of cumulus and stratocumulus. Note the consistently flat base.

Photo by Pan American Airways System

TYPICAL POLAR-FRONT STORM CLOUDS. In their vastness and in the clearly defined organization of their components, the storm clouds in this photograph and the one on the opposite page are typical of all the storms which progress from west to east along our polar front.

As soon as a mass of air leaves its source, it begins to change its physical properties; and the weather phenomena which develop within it depend upon the influences sustained on the journey. Air masses may be classified according to the source whence they obtained their fundamental properties: (1) Arctic—from Arctic snow and ice; (2) Polar—from anticyclones in high latitudes; (3) Equatorial—from the doldrums; and (4) Tropical—from subtropical anticyclones.

Photo by Pan American Airways System

MORE TYPICAL POLAR-FRONT STORM CLOUDS.

Massive clouds of this kind indicate instability. It is evident from its rounded top and cumulus form of development that the cloud pictured above is in a state of vigorous agitation. Of great vertical extent, it is the product of condensation of moisture from rising air currents, the temperature and humidity of the lower air governing its base. Its upper and lower margins are well defined. With the light of the sun falling sideways, deep shadows are cast which reveal the thickness of the cloud. Close to the base are ragged fractocumulus, known as fair-weather clouds when they occur as small broken or detached clouds following a cyclone.

CHAPTER VII

THE SIGNIFICANCE OF CLOUDS FOR TOMORROW'S WEATHER

What, then, is the significance of clouds in impending weather? As sentinels of weather they are without rival. They are an immediate and open expression of the physical processes taking place in the atmosphere. With some success man can differentiate cloud forms and interpret their fleeting characters. Instinctively he turns his eyes upward to the sky to learn the sequence of change in atmospheric development which comes as part of his inescapable heritage and condition. An accurate description of the type and amount of clouds plays an important part in weather analysis and forecasting. Primarily clouds are potential bearers of rain, and down through the ages they have been so regarded by man, to whom blue skies are reassuring. When clouds are forming we ask ourselves, "What do they foretell? Will the day be fine, fair, or foul?" Should the sky be cloudy and gray, we feel foreboding and intuitively anticipate the worst.

Weather is merely the state of the atmosphere relative to temperature, humidity, and motion over a short period of time in a particular area. It comes to us warm or cold, wet or dry, in periods that vary both in duration and in character. Moist and cooler air invading a region that is sunny and dry gives rise to an aerial conflict; and wet weather often spreads over us with or without any electric clash.

Climate, the prevalent or characteristic meteorological conditions of any place or region, comprises the average weather conditions over a long period. In comparison with the climate pertinent to the interior of a continent, a marine climate enjoys small annual and daily ranges of temperature. And as any climate, continental or marine, provides an element of delightful uncertainty, so clouds are capable of many transformations, each possessing its own significance and application. For example, if a summer day is anticyclonic, or fine, clouds may float in the blue sky; or they may increase in size, multiply, and finally develop into a thunderstorm. Occasionally there may be long threads or bands of clouds, or the sky may be entirely cloudless. Again, certain types of cloud may obliterate the sky for a day without any rain's falling; whereas others, more broken in character and darker at their bases, may cause frequent and heavy showers to fall—in particular such clouds are associated with that constant heavy rain which is found within a cyclone.

CLOUD STABILITY

Before discussing cloud stability, we may observe that the atmosphere, or mass of air surrounding the earth, is considered stable when the vertical distribution of temperature is such that a particle of air will resist displacement from its level. In the science of thermodynamics the word "adiabatic" applies to a process of temperature change during which no heat is communicated to or withdrawn from the body or system concerned. Adiabatic changes of atmospheric temperature—sometimes described as dynamic heating and cooling—occur as a result of compression or expansion accompanying an increase or decrease of atmospheric pressure. Accordingly, when the air is unsaturated, the lapse rate for stability will be less than the dry adiabatic lapse rate; when saturated, the lapse rate will be less than the saturated adiabatic lapse rate.

On the other hand, atmospheric instability occurs when the vertical distribution of temperature is such that an air particle, if given an upward or downward impulse, tends to move away with increasing speed from its original level. Thus in the case of unsaturated air the lapse rate for instability will be greater than the dry adiabatic lapse rate; in the case of saturated air the lapse rate will be greater than the saturated adiabatic lapse rate.

Meteorologists now prefer the term "lapse rate" to "vertical temperature gradient." The word gradient refers to a change of value of a meteorological element per unit of distance. In meteorology the gradients commonly discussed are the horizontal gradient of pressure and the vertical gradient of temperature, with the term "gradient wind" referring to a wind of the velocity necessary to balance the pressure gradient.* The direction of the gradient wind is along the isobars (lines on a chart or diagram drawn through places or points having the same barometric pressure,† except for effects of friction near the surface of the earth,

* Pressure gradient is the decrease in barometric pressure per unit of hoizontal distance in the direction in which the pressure decreases most rapidly.

† Isobars drawn on a weather chart show the horizontal distribution of atmospheric pressure reduced to sea level, or the pressure at some specified altitude.

and the velocity is so adjusted that there is equilibrium between the force pressing the air toward the region of low pressure and the centrifugal action to which the moving air is subject in consequence of its motion.

Cloud forms differ greatly in stability according to their types. Whereas, for example, stratus clouds are stable and relatively static, cumulus clouds are characterized by turbulence, or irregular motion of the atmosphere. The more sharply defined the upper surface of stratus, the greater the stability. When fog or cloud at the earth's surface is in the process of changing to cumulus cloud, one-half hour may mean a difference between a densely foggy morning and bright sunshine. Without condensation nuclei, such as minute grains of dust, clouds are impossible.* If there are less than 200 in a cubic centimeter of air, there can be no fog or cloud. Through the medium of the "dust counter" it is possible to determine approximately the number of dust particles or condensation nuclei per unit volume in a sample of air. The weight of visible water in a cloud may vary from 0.1 to 5 grams per cubic meter, or from 1.5 to 8 grains per cubic foot.†

CLOUD SEQUENCES

1. In the path of a cyclone
2. When the cyclone passes
3. Changeable weather in intervals between cyclones
4. Under anticyclonic skies (cyclone in reverse)

1. IN THE PATH OF A CYCLONE: Best known of all cloud sequences are those which ordinarily precede and accompany the passage of a cyclone, or storm. Their development is interesting, and their presence may prove more or less ominous, depending upon the intensity of the disturbance which they foretell.

What is the first indication of the approach of a disturbance? High overhead, under the canopy of a serene blue sky, we observe some faint lines and wisps of a delicate threadlike white cloud known to the sailor as "mare's-tail" and to science as cirrus. As we watch these beautiful feathery creations drift along—generally at a height of about 5 miles

* In the meteorological sense, "nucleus" is used to refer to a particle upon which condensation of water vapor occurs in the free atmosphere in the form of a water drop or ice crystal.

† The metric system is applied to upper air soundings and the British system of units to all surface weather. In the absence of a much-needed uniform system of units, it is necessary to use both the metric and the English systems. See Table of Equivalents.

and from points west to east—they appear at first to thicken gradually into a somewhat confused web, or to assume varied shapes such as isolated tufts, thin filaments on a blue sky, threads spreading out in the form of feathers, or curved filaments ending in tufts. Finally, as the storm draws nearer, a more definite transformation occurs, the picture changing into the uniform white sheet of cirrostratus. A few hours more, and this white sheet becomes grayer and denser, until eventually it assumes a dark blue-gray color with the sun shining through it as a mere dim spot of light. Considerably lower than was the original cirrus—perhaps no more than 2 miles up—the cloud is now altostratus.

In the interval between the first appearance of cirrus high in a blue sky and the gradual transition into cirrostratus and, now, altostratus, the central portion of the storm is overhead, and it is a matter of only a very short time before nimbostratus, the rain cloud, appears and the rain commences to fall. As a rule the first dark fragments of nimbostratus can be seen approaching below a dense pall of gray altostratus and—as so often—veiling the sun. A streak of this cloud extending in an unbroken layer over the sky may therefore be regarded as a harbinger of continuously moderate rain. From the time the rain cloud arrives until the passage of the "trough," an elongated area of low barometric pressure familiarly called "low" on the weather map, rain falls more or less continuously.

2. WHEN THE CYCLONE PASSES: Once the center of the cyclone has passed, two things happen: the sky begins to clear; and, instead of rain cloud, nimbostratus, we have broken or hapless shaggy portions of various types of cloud. From some of these types—notably cumulus and cumulonimbus, massive heaps of clouds resembling mountains sheering into the blue—occasional showers fall. As the atmosphere becomes more settled, or less cyclonic, the cumulus, or "heap" clouds—lowering, perhaps, around the horizon—may assume the form of long bands of stratocumulus. Ragged stratocumulus rolling in long banks at a height below 7,000 feet before fibrous altostratus are characteristic of breaking clouds in the rear of a cyclone. Should no further disturbance be approaching or in process of formation near by, in short order the sky will become cloudless and revert to the reflected congeniality of Nature at ease in her happiest moods.

The foregoing is the most common sequence of clouds when a cyclone is passing directly over an area. But more often than otherwise storms do not pass directly over an area, but skirt it, passing to the north or south of the observer. We may then find ourselves on or outside the limits of the actual storm. For example, the British Isles are frequently skirted by Atlantic storms which to the north pass onward to Scandinavia, and to the south move up the English Channel, traveling across Denmark to the Baltic. Similarly, midcontinental storms in America pass eastward across the Great Lakes and Canada, or southeastward over the Atlantic, skirting neighboring areas.

3. CHANGEABLE WEATHER IN INTERVALS BETWEEN CYCLONES: When, on the margins of a disturbance, the cloud sequence differs from that described above, an assortment of clouds in detached patches may be anticipated, with a few of the major cyclonic types predominating. The general barometric distribution will savor of the "unsettled" variety so common in the forecast. Such conditions, however, do not always presage bad weather, but sometimes precede thunderstorms and are often experienced on hot or sultry summer days or in mild winter weather. In these circumstances, what cloud transition may we expect? Normally the classification may then consist of mixed upper clouds—either cirrus and cirrocumulus (probably 20,000 feet high) in long parallel bands apparently radiating from a focal point or broken sheets of "mackerel," such as the cirrocumulus and the altocumulus. Here and there may be observed portions of the highest cloud types, perhaps some isolated patches of cirrus, moving—as cirrus always does—away from the center of the storm. To the meteorologist, therefore, threadlike wisps of white cirrus are a reliable guide to what is happening back in the mechanics of the weather and of change to follow. Occasionally in the realm of the higher clouds in the intermediate levels of the atmosphere and distinguished by a "double-wave" system, altocumulus may be observed to close up, or graduate, into a well-defined long sheet. Often, too, under such skies the weather becomes more unsettled, and slight to moderate rain may be expected to fall. Thus, banks of altocumulus seen at sunset on the southern margins of a cyclone usually presage warm and squally weather. Cirrostratus and altostratus, with cirrocumulus and altocumulus tops, are characteristic of overflow from intense cyclones. The shadowy parts are altostratus and the larger rounded tops, altocumulus.

4. UNDER ANTICYCLONIC SKIES (CYCLONE IN REVERSE): Passing from cyclonic (stormy) to anticyclonic (fine-weather) skies, we find Nature's handiwork in reverse. The outlook will be accordingly. When, in the technical sense, the weather is anticyclonic, or

typical of skies often seen after a cyclone has passed over and the weather is improving, we are in a region where pressure is high and winds are gentle or calm. It is recognized in weather forecasting that the currents of air associated with anticyclones influence the course, or path, of a cyclone to such an extent that the position of the anticyclone in relation to the cyclone has a decided bearing, not only on the dirction of movement, but also on the speed of the cyclone. In the Northern Hemisphere the latter moves so as to keep the area of high barometer to the right of its course. In summer anticyclonic weather is for the most part cloudless; but in still, cold weather in winter the skies may be very cloudy with stratocumulus—a single type of low stratified cloud in long banks—predominating. It is a fairly low cloud consisting of irregular dark masses, somewhat circular or oval in structure, and flecked with patches of sunlight, or inlets where it would seem as if the sun's rays filtered through. A feature of the winter skies in anticyclonic regions is that cloud sheets of this class may darken the sky for days at a time without any rain falling. When, as not infrequently, they play hide-and-seek with the sun, they may present features of compelling beauty.*

* In a most interesting series of cloud photographs, Dr. G. A. Clarke, of the Observatory at King's College, Aberdeen, Scotland, illustrates stratocumulus clouds in waves at sunrise at a height below 7,000 feet—an uncommon variety of this type of cloud.

Courtesy, U. S. Weather Bureau

A CYCLONE IS APPROACHING. This beautiful plumelike cirrus is part of the cloud system of eastbound frontal storms. This plume, the only one in the sky, did not increase during the afternoon and vanished at sundown.

Courtesy, U. S. Weather Bureau

THE CYCLONE DRAWS NEARER—BAD WEATHER IS THE OUTLOOK. The cirrus are detached portions, and with them are cirrostratus formed from evaporating cirrus. Note the fibrous structure, like a tangled web. Cirrus clouds found in connection with altostratus also spell bad weather as a rule. Heavy snow may fall from such a combination. When altostratus brings heavy rain, the cloud layer will grow thicker and lower, becoming nimbostratus.

Observe the silky whiteness of the edges of this delicate weblike formation, the transparency of which depends upon the degree of separation of the ice crystals of which it is composed. Cirrus is lit up by the sun long before other clouds and fades out much later. Before sunrise and after sunset, it meets the eye as if colored bright yellow or red. Some time after sunset, however, it changes to gray. Near the horizon, at any hour of the day, cirrus is often of a yellowish tint, owing to the distance of the cloud and the great thickness of the air traversed by the rays of light.

Official Photograph, U. S. Army Air Forces

THE FRONT OF THE CYCLONE IS OVERHEAD—LOOK OUT FOR RAIN. Fragments of nimbostratus below gray altostratus. The typical nimbostratus is a low shapeless rainy layer, dark gray and seemingly feebly illuminated from inside. It is often seen with a fractocumulus roll along the horizon. Precipitation is in the form of continuous rain or snow. The convention is made that nimbostratus hides the sun and moon in every part of it; whereas altostratus hides them only in places behind its darker parts but they reappear through the lighter parts of the cloud.

The dark masses of fast-moving cloud—the outer parts of the main cumulonimbus mass to the left—bring variable and gusty winds. These ragged "scud" clouds, fractostratus and fractocumulus, are in process of merging into the main cloud deck above. Sometimes nimbostratus may form out of heavy and threatening stratocumulus.

Official Photograph, U. S. Army Air Forces

THE CYCLONE HAS PASSED OVER—THE WEATHER IMPROVES. Tops of stratocumulus are arranged in long banks, below about 7,000 feet. They consist of a layer or patches of laminae, globular masses, or rolls. The smallest of the regularly arranged elements are fairly large; they are soft and gray with darker parts. Cumulus of fine weather, as seen from above, are arranged here in stratified layers of heaped-up bulbous rolls. Stratiform is broadly applied to all clouds arranged in unbroken layers or sheets. Stratiform clouds of one kind or another are often confused with flat, elongated stretches of altocumulus.

After the passage of a warm front, the warm sector may be swathed in fog or low clouds such as stratus, appearing in sheets or layers near the horizon. They usually form fogs. Unless the cold front has to some extent joined forces with the warm, or follows immediately after it, the sky may be expected to clear partially, the rain to cease, and the surface air to grow warmer.

Courtesy, International News Photos

CHANGEABLE WEATHER BETWEEN STORMS. Here we have mixed upper clouds, cirrus and cirrostratus in long parallel bands at a height of about 20,000 feet. With the exception of the line squall, cold-front clouds do not extend as high or as far as warm-front clouds. The passage of a cold front is often followed by a clearing of brief duration, after which follow the weather phenomena characteristic of the cold air mass. As a rule cold-front clouds appear on the horizon rather suddenly and move rapidly across the sky. When cirrus disappears slowly, the indication is for fine weather; when it grows denser, it is often the harbinger of a general rain and of a storm coming in the same direction as the clouds are moving. Heavier and lower clouds will follow in its wake.

Courtesy, U. S. Weather Bureau

CHANGEABLE WEATHER. This remarkable picture, taken on November 15, 1941, shows the following mixture of high clouds such as originate from thunderstorm tops: cirrocumulus at the upper left; cirrus at the right; cirrostratus in the center; and stratocumulus at the bottom. To all appearances they diverge from a radiant point, at a height of about 20,000 feet. The outlook is for changeable weather.

By studying the dew point and the forms of cumulus clouds, it is possible to foretell the weather for the ensuing few hours. Observe what may be happening in the upper parts of the clouds. If there are no towers, there is no likelihood of rain. If there are towers, rain may develop. If some of the clouds reveal the presence of ice crystals, precipitation is certain to follow soon.

Photo by Hans Groenhoff

A THUNDERSTORM IN THE MAKING. A well-defined thundercloud top showing cirrus becoming detached. Thunder is one of the most awe-inspiring of all meteorological phenomena, but of no great moment as a prognostication of weather to come. Convection is responsible for thunderstorms.

Photo by Hans Groenhoff

THE STORM HAS PASSED, BUT CHANGEABLE WEATHER WILL CONTINUE. Cirrus and cirrocumulus arranged in bands indicate changeable weather in intervals between storms. Detached perpendicular masses, they spread out in lines in one or two directions, and sometimes appear in ripples. In this photograph they diverge as from a "radiant point."

Photo by Hans Groenhoff

CONDITIONS ARE UNSETTLED. Altocumulus clouds in the intermediate levels of the atmosphere, arranged in globular masses. Solid parallel rows or banks of altocumulus are common forerunners of cold fronts. Like cirrus, they frequently indicate the approach or continuation of bad weather.

As the front approaches, the barometer starts to fall gradually and remains unsteady. The wind shifts in direction. Above the western horizon more and more clouds, dark and ominous, continue to arrive. Directly underneath them will be a slanting gray screen of rain, snow, or hail. Showers are brief though heavy.

Before heavy rains, especially at the approach of a thunderstorm, each cloud becomes larger than the former, and all are visibly increased in size.

The weather of the Northern Hemisphere is to a very great degree determined by large passing cyclones. Over the interior of the continent, the cloudiest season is summer, but the amount is never very large. Otherwise winter is the cloudiest season, with a fairly high mean amount. Rainfall on the whole decreases steadily from Equator to poles.

Photo by Hans Groenhoff

UNSETTLED OR TRANSITIONAL WEATHER. It may or may not rain. Stratified cloud formations of this type indicate unsettled weather. Altocumulus in banks and ripples appear at the top left of the photograph, with altostratus and fractocumulus below. They will not last long if they help temper a subtropical sun.

"When the dew is on the grass, rain will never come to pass."

So runs the proverb, and there is a modicum of truth behind it. Dew forms heavily when the state of the air is such that rain can scarcely fall; on still nights, when conditions are such that rain is imminent, dew does not appear.

Photo by American Airlines, Inc.

WILL IT THUNDER OR NOT? The outlook is uncertain; the weather may continue fine or may develop into a thunderstorm. The photograph shows an isolated cumulus in process of development. Formed by a diurnal ascensional movement, this cloud may or may not bring a thunderstorm. In the upper left of the picture is an altocumulus cloud in the shape of an anvil.

The shifting currents of the ocean of air are such that when a sheet of high cloud develops over cumulus clouds, the latter may disappear slowly or dissolve by a process of general shrinking. In disappearing in this fashion, they renew the cycle of fair-weather cumulus, the flat cumulus humilis. In other words, when a warm-front cloud system approaches, cumulus clouds in the cold air will shrink and fade away.

As a rule, fair-weather cumulus hovering at heights from 2,000 to 9,000 feet wax and wane with the sun. In the same manner some cumulus clouds, engulfed in the downdraft of air which is dynamically heated along the lee side of a mountain, evaporate so quickly that they seem to vanish. Partially evaporated remnants of such clouds are known as fractocumulus.

Official Photograph, U. S. Army Air Forces

THUNDERSTORM OR CLOUDBURST MAY BE NEAR.

This thunderhead, distinguished by its flat, dark base, is typical of summer cumulus. Wisps of spindrift around the summit of the thundercloud before the storm breaks are characteristic. In the right center is another cumulonimbus in early stages of growth. In the upper left are heavy cumulonimbus and the low ragged clouds of bad weather.

Cumulonimbus is a cumulus cloud which has grown until rain is falling from it. It is usually accompanied by lightning and thunder, and sometimes hail. Its turreted or anviled top is generally surmounted by a sheet or screen of fibrous appearance, having at its base a cumuliform mass of clouds similar to altocumulus and dark fractocumulus. Inasmuch as they form in unstable air, all towering cumuliform clouds indicate instability.

Courtesy, U. S. Weather Bureau

WITHIN 12 TO 36 HOURS IT WILL RAIN OR SNOW.

Mare's-tail cirrus with tufted ends is often seen at a height of 30,000 feet. The true cirrus, or mare's-tails, are fibrous in appearance and stream out in the direction of the winds in the upper levels, and indicate the approach of a storm.

"Trace in the sky the painter's brush;
The winds around you soon will rush."

Photo by F. Ellerman; Courtesy, U. S. Weather Bureau

A STORM IS APPROACHING. Cirrus merging into cirrocumulus. The long, wispy clouds called "mare's-tails" and the sky flecked with cirrocumulus, known as mackerel sky, are the result of the high-level overflow of air in front of a cyclone. The pattern is caused by a single or double undulation of the cloud sheet. Fibrous in appearance, the cirrus stream out in the direction of the upper winds and often presage a thunderstorm.

Photo by W. J. Humphreys; Courtesy, U. S. Weather Bureau

BAD WEATHER IS COMING. Typical fibrous or threadlike cirrus, arranged in bands and connected with altostratus, are usually forerunners of bad weather. The storm is much nearer than in the photograph on page 184. Depending upon the intensity of the storm, its approach and transition are gradual or rapid. Warm, light air will usurp the place of the cold, dense air above; surface winds will blow largely from the south, southeast, or east; the barometer will fall gradually while the warm air continues to replace the cold.

Again, as the front draws closer, the clouds, becoming heavier, will sink until equilibrium is re-established. Continuous rain or snow, at first light but later heavy, may fall from this layer through the clouds below. In excessively moist and turbulent air, altostratus will descend and thicken into nimbostratus. The depth of cloud necessary to create fine rain is as little as 1,000 to 2,000 feet.

Photo by L. A. Boyd; Courtesy, U. S. Weather Bureau

A STORM IS PORTRAYED. Tufted cirrus and altocumulus portray a storm. The clouds in the upper and left parts of the photograph are tufted cirrus, with isolated patches of altocumulus below and reflected light beneath. Below the detached fragments lies a rapidly thickening sheet of altocumulus caused by local convections in a layer of unstable air.

If "last night the moon had a golden ring; tonight no moon we see," the significance may be that cirrus, moving from southwest or west, heralds foul weather—the approach of a warm front. When cirrus hangs, a lone traveler in space, in the middle of a high, it is of fair-weather complexion. But if it thickens, as in the circumstances it is prone to do, to cirrostratus, and cirrostratus in turn thickens and lowers to altostratus, a warm front is well on the way, bringing its normal sequence of cloud and frontal development.

Courtesy, U. S. Weather Bureau

A STORM IS ABOUT TO BREAK. Low-lying nimbostratus, and cumulonimbus heavy with rain or snow, are sailing before a west wind, trailing off to dense altocumulus in the distance. They are remnants of cumulus clouds associated with the passage of a general, or cyclonic, storm. The strong vertical velocities which produce the cumulus type of cloud occur when the air is unstable. The thunderstorm is evidence that the air is returning to a more stable state. Nimbostratus, also associated with a cyclonic storm, is largely a product of cooler air in front of a storm center, or of humid air rising over an obstacle in its path. Often this cloud sheet comes into being in a morose, hazy sky through the lowering of a sheet of altostratus. In rare instances it may evolve from a sheet of stratocumulus.

Official Photograph, U. S. Army Air Forces

MACKEREL SKY—A THUNDERSTORM MAY BE NEAR. This type of sky frequently precedes a thundersorm. In mild weather in winter, or on warm summer days with a tendency to sultriness, cirrocumulus clouds may be seen arranged in groups and often in lines.

These delicate white flakes of cloud, merging here and there into denser areas of cirrostratus, are probably 6 miles high. The individual puff balls of cirrocumulus appear much smaller than those of altocumulus and are not thick enough to cast shadows or show dark undersides.

If the upper parts of a towering cumulus disintegrate before consolidating into a single sheet, it is probably because dry air aloft has robbed the cloud of its moisture. Very dry air underneath a rain cloud may dry up the rain before it reaches the earth.

Photo by F. Ellerman; Courtesy U. S. Weather Bureau

MACKEREL SKY — LOOK OUT FOR THUNDERSTORMS. The sky is flecked with cirrocumulus. A summer day is hot and sultry, a winter day mild.

Photo by Hans Groenhoff

THE WEATHER IS IMPROVING. Stratocumulus clouds in long banks or rolls, below 8,000 feet, are sometimes seen in skies after a storm has passed and the weather is improving. These are fair-weather stratocumulus. When, however, very dark rolls, 1,000 to 2,000 feet high, stretch menacingly along the gradient wind in the outer parts of an intense tropical storm, they are appropriately called "foul-weather stratocumulus."

Courtesy, U. S. Weather Bureau

THE FRONT OF THE STORM IS OVERHEAD—EXPECT EARLY RAIN. Parts of nimbostratus and swelling cumulus without shape and with ragged edges veil the sun below a dense pall of gray altostratus. As a rule this sky, associated with chaotic thundery conditions, is followed by moderate and steady rain, with the altostratus constantly increasing and lowering. The usual evolution is as follows: After the change from cirrus to cirrostratus and then to altostratus, the last grows denser, darker, and lower, totally covering the sky and without distinctive form, until finally steady rain or snow falls from it. Below this cloud layer is generally a progressive development of fractocumulus or fractostratus, at first isolated, then fusing together into a layer in the insterstices of which nimbostratus can be seen.

Photo by H. T. Floreen; Courtesy, U. S. Weather Bureau

HEAVY SHOWERS OR A THUNDERSTORM. This cumulonimbus, photographed at Cheyenne, Wyoming, shows a well-formed anvil head in a thundery sky. Thunderstorms are brief and local as compared with the general cyclonic storm, which often lasts for several days and successively gives rain or snow to one part of the country after another as it sweeps from west to east. An average thunderstorm may last only some 2 hours, and be a mere 30 to 70 miles in extent. Thunderstorms are usually heralded by certain premonitory signs—a steadily dropping barometer; calm, heavy air pervaded by a sulphurous odor; stifling heat and an abnormal silence over the area. Then lightning escapes in sudden jets; rain, frequently mixed with hail, pelts the earth to the accompaniment of thunder—the result of a steep pressure wave caused by a sudden expansion of air created by a fast discharge of lightning.

Courtesy, U. S. Weather Bureau

WARM, SULTRY WEATHER WITH POSSIBLE THUNDERSTORMS. These clouds come about through the ascent of air from close to the earth's surface up to relatively great heights and its subsequent cooling by expansion to temperatures below the dew point. The most frequent type of low cloud is the early-afternoon cumulus. In this photograph, altocumulus castellatus and tall cumulus castellatus predominate. The thick, towering cumulus in the left foreground is a forerunner of the thunderstorms and squalls of summer. When thunderheads appear in the west and the sky blackens in the northwest on a warm, sultry day, rain is approaching—hence the saying:

"When clouds appear like hills and towers,
The earth's refreshed by frequent showers."

Photo by Hans Groenhoff

LOOK OUT FOR WARM, SQUALLY WEATHER. Altocumulus as seen at sunset on the southern borders of a cyclone. Irisation along its thin, translucent edges is characteristic of this type of cloud, which may be derived from a spreading out of the tops of cumulus. This cloud formation indicates instability, at least partial, in the cold air and is part of the system of rapidly moving cold-front clouds. Extending for hundreds of miles to the rear of a surface front, such clouds sometimes linger for a day or more before dispersing. Nevertheless, the frontal cloud area is comparatively narrow; and if the front moves at high speed, clearing may occur within half an hour of the front's passage.

Official Photograph, U. S. Army Air Forces

SHADOWS STREAK THE SUNLIT SKY. It is a good indication of a coming storm when the sky is overcast with a very thin whitish veil through which the sun shines brightly—provided this whitish veil thickens into a gray one within the next hour or two. The sun will be scarcely visible through the gray veil, and there may be rain or snow within a few hours. The gray veil, altocumulus undulatus, locally more or less scaly, is a lower cloud than the white veil, cirrocumulus; and between the elevations at which the two types form, there are often clouds of great beauty to be seen such as those which compose the mackerel sky.

Sometimes, when bunched high clouds are below the horizon, the sunlit sky becomes streaked with shadows.

Courtesy, U. S. Weather Bureau

THE WEATHER MAY NOW IMPROVE. These are breaking clouds in the rear of a cyclone, and the weather may now improve, at least temporarily. Ragged rolls of stratocumulus are shown underneath altostratus. The final clearing may, however, be delayed by intermittent showers and cloudiness, especially over mountainous terrain—as, for instance on the slopes of the Alleghenies or the western slope of the Rockies, overrun respectively by cold, moist polar and polar-Pacific air masses. In both cases, the cold air mass being moist and unstable, storms or squalls of snow and rain may recur at short intervals or continue for many hours after the front has passed.

Unstable air masses give cumuliform clouds; stable, warm air gives stratified clouds. Precipitation will be showery in the first case, steady in the second.

Courtesy, International News Photos, Inc.

FAIR WEATHER. About 11 o'clock the sky will be cloudless. When early-morning fog is scattered by convection, or the ascension of air currents, the sky will clear. When fog is in process of changing to cumulus cloud, a half-hour may mean a difference between a densely foggy morning and bright sunshine. This photograph of summer fog streaming over the hills of the coast might be described as Nature's thwarted attempt at rain making.

A fog and a cloud are identical in structure, although the former is due to thermal conditions of the earth's surface and the latter to the dynamic cooling of ascending air. The presence and persistence of fog depend upon how far the temperature of the water differs from both air temperature and dew point. The closer the dew point to the air temperature, and the farther the water temperature from both, the more probable and persistent will be the fog. The edges of a fog zone are seldom well defined and tend to merge with broad haze zones.

Photo by American Airlines, Inc.

THE DAY WILL BE SUNNY AND WARM. Sometimes a pilot encounters several distinct types of cloud formation. In this photograph there are cirrostratus clouds with a line of altocumulus, and altostratus directly beneath. Scattered cumulus appear in the lower foreground. When several types of cumulus lie in different layers, they sometimes scatter or disappear under a warm sun. If clouds gather rapidly, the rain will be mere passing showers. But if they thicken and extend themselves gradually, the rain to follow will be persistent. It is generally true of all clouds of the cumulus, as opposed to the cirrus, type that "the higher the clouds, the fairer the weather." Much cooling is required to form clouds at high levels, with the result that they do not contain enough humidity to produce any appreciable amount of rain or snow.

Courtesy, U. S. Weather Bureau

A SUNRISE FORECAST. The storm has passed over, and quiet, cold weather will continue. At sunrise in winter, stratocumulus may be observed in waves or in great rolls arranged in compact parallel lines below 8,000 feet. This cloud, not a common variety, may be seen in the quiet cold of winter. Clear, light-red skies, whether morning or evening, promise fair weather; somber red, cloudy skies betoken a storm to come. In the latter case the air is usually very humid, and the aspect sullen and lowering. A gray morning sky implies a dry atmosphere, hence indicates a quiet fair day. The rising sun evaporates the droplets which cause the gray; therefore any ascension of the humid air is not likely to bring rain since, in rising, it mixes with the much cooler air above.

Official Photograph, U. S. Army Air Forces

A SUNSET FORECAST. The weather may be warm and squally. At sunset, when the observer is on the southern border of a cyclone, banks of altocumulus floating in an oval or lenticular formation may indicate warm and squally weather.

Lenticular clouds exist at all levels, from cirrostratus to stratus. Ovoid in shape, with clear-cut edges and sometimes irisation, they are especially common on days of strong, dry winds over rough country.

It is characteristic of this chaotic sky, with altocumulus in several sheets at different levels, that detached masses of altocumulus spread out and take on the appearance of small waves or thin, slightly curved plates. Radiation is responsible for the gray of the morning sky; convection for the gray of the evening.

The photograph shows the cloud formation west of Mt. Rainier.

Photo by C. E. Deppermann; Courtesy, U. S. Weather Bureau

SPRING IS HERE. Cumulus congestus is here seen under stratocumulus. The vertical currents within cumulus congestus are more violent than in their smaller brothers, cumulus humilis. They are thick clouds, with dome-shaped upper surfaces exhibiting protuberances, and their bases are horizontal at condensation level. The "protuberances," which extend upward from the top of the main cloud, are signs of isolated convection currents of high velocity within the principal rising body of the cloud. They appear at first as slight, unobtrusive bulges on the rounded top of the cumulus, then suddenly shoot upward with remarkable speed. While several of them merge simultaneously, the balance of the cloud proper will grow, mushroom-fashion, between them. Like cumulus humilis, cumulus congestus seldom cover more than half the sky; but they may reach heights between 2 and 3 miles. In brief, cumulus congestus are towering creations which grow frequently into cumulonimbus; whereas cumulus humilis are afternoon clouds of fair weather.

Official Photograph, U. S. Army Air Forces

AN AUTUMN SCENE INDICATING MODERATE N TO NE WIND. Typical sheets of stratocumulus or altostratus, with slight mammatus structure, fed by overflow from local stratocumulus below. Ragged stratocumulus rolls underneath fibrous altostratus are characteristic of breaking clouds in the rear of a cyclone. The rolls, arranged in parallel lines, are dense and dark; but in the intervening spaces, especially with the lifting of the storm, the roll cumulus becomes much lighter and patches of blue sky are visible.

Stratocumulus generally gives the appearance of a gray layer broken up into irregular masses, with smaller masses grouped on the margins in flakes like altocumulus. Altostratus, on the other hand, may exhibit all stages of transition from altostratus to cirrostratus, but its normal height is about half that of cirrostratus.

The coasts bathed by the waters of the Gulf Stream have greater cloudiness in winter than in summer. Most of continental North America is too cold in winter to add much heat to southward-moving polar air.

Photo by Pan American Airways System

A WINTER SCENE INDICATING A NORTHWEST WIND. Ragged altocumulus and stratocumulus rolls, with stratus underneath, scurrying before a northwest wind. Air masses which have moved swiftly and directly from polar regions have maximum instability. As in this instance, cold air sweeps overhead from north or northwest; the wind shifts from southwest to west or northwest and increases gustily to gale force or above.

After passage of the cold front—perhaps an hour or two later—the barometer will rise, showers will become lighter and less frequent, and the clouds will begin to scatter. The final clearing up may be delayed some hours, possibly a day or two, if the cold air mass proves to be exceptionally moist and unstable.

Good flying conditions may exist between the cloud layers of two air masses which have not merged. This frequently happens when a front is weak; the base of the overcast sky as low as 1,000 to 1,500 feet; and the top some 15,000 to 20,000 feet high.

CHAPTER VIII

FOG AND VISIBILITY

Two minor ingredients of earth's atmosphere—water vapor and dust particles—are the principal sources of low or reduced visibility. Dust particles derived from the action of winds on the earth's surface, from volcanic ash, from salt remaining after ocean spray has evaporated, from smoke emanating from cities, forest and other fires, and in higher latitudes from meteors, are partly responsible for poor visibility; but the principal cause is condensation of water vapor derived from evaporation from the oceans and other bodies of water, and also from plants and the soil.

FOG

In brief, the production of fog is governed by atmospheric pressure, temperature, humidity, and dust content; also by winds and in minor degree other agencies. As W. J. Humphreys has observed, "Dust, moisture, and some cooling process are the three essential factors in all natural fog and cloud formation."

Fogs indicate settled weather. A morning fog frequently breaks away before noon. Convection-caused fogs will usually clear about 10 a.m. Refraction layers in the atmosphere often assume the appearance of fog.

Owing to a preponderance of comparatively warmer and more moist air, spring and summer generate more fogs than either fall or winter. Fog occurs at some time over most of the earth's surface. In winter, winds blowing from the sea upon land are likely to produce fogs. An east wind upon eastern coasts and a west wind upon western coasts are the chief sources of fog, which is thus the most usual result when warm, humid air passes over cold surfaces—namely, a cloudy condensation near, or resting on, the land or sea.

Professor Alexander McAdie says in the "Cloud Atlas" of his day, "A cloud is nothing but a fog that by virtue of a slight excess of heat has developed a lifting force and so rides high. . . . Whenever cold and warm streams meet, be they of water or air carrying water in the invisible form, there will fog form; and the density be proportional to the temperatures involved."

London fogs and those of great cities and manufacturing areas in general are greatly increased by reason of the particles of soot issuing from chimneys. Each soot particle is a center of condensation. A record of city fogs covering many years shows the effect of the smoke nuclei as a stimulus to condensation with, as in recent years, an appreciable fog decline where coal has been gradually supplanted by other heat- and power-producing agencies. On the other hand, much of the Newfoundland fog is due to ice and cold water imported from the Arctic regions by the Labrador Current. These icebergs are likely to be centers of dense fog, especially in summer. More particularly, however, are they caused by the warm and cold ocean currents or drifts which meet around Newfoundland. When the winds are from an easterly quarter, their temperatures are lowered and their moisture condensed as they pass over the cold Labrador Current to the west.

Fogs are more frequent on the Pacific coast than on the Atlantic, due to the prevailing wind direction's being from west to east. On the Atlantic coast the winds come from the land and are consequently less humid. Increasing gradually from the eastern shores of Long Island to the great breeding ground of fog over the Grand Banks, moist winds from the area of the Gulf Stream, blowing over the Labrador Current in the vicinity of Newfoundland, produce fog. As the Gulf Stream converges toward the region of the Grand Banks, in a great eddylike movement of cold water in the Labrador stream southeast of Newfoundland the ratio of fog prevalence increases. It is not alone the density of the phenomenon, but also its frequency that makes it especially formidable off this portion of North America. Fogs rarely occur near the Azores or between them and Portugal. Many of the New England coastal fogs are due to the intermingling of moist Atlantic air currents with cooler areas more or less snow-clad.

Over the coastal areas of the North American Continent, and extending over 200 to 300 miles of ocean eastward from the same coastline, fog may be a sea fog blown landward by winds, or it may be a cyclonic fog created on land. Alternatively when moist, fogless air blowing in from the sea interacts with colder currents over land, the warm air current may turn its moisture into fog.

An ordinary cyclonic fog sometimes occurs ahead of a cyclonic whirl of moderate intensity advancing toward the Atlantic seaboard from the interior of the continent. Mixing of cold air from the northwest with warm and moist air from the ocean may cause the production of either fog or rain.

Although the conditions under which fogs are formed may vary greatly in different parts of the world, the most common set of conditions engendering them are as follows:

1. Land fog: (1) moist and warm soil and a low, flat area of land; (2) cold air with an absence of circulating wind.

2. Sea fog: The effect or result produced in the atmosphere by the cooling of a warm air surface in contact with the substantially colder water of the sea.

In the great majority of cases, fogs extend to a low altitude. The top of a fog layer is definite, and above it the relative humidity decreases rapidly. Temperature increases from the surface to the top of the fog and then decreases. No matter how dense fog may be, the actual water content is remarkably small. The fog consists of numerous droplets of water so small that they cannot be readily distinguished by the naked eye. It is estimated that a block of fog 3 feet wide, 6 feet high, and 100 feet long would contain less than 1/7 of a glass of liquid water. W. J. Humphreys describes fog as "a great swarmlike assemblage in the surface air of hundreds of thousands of droplets per cubic unit so minute that it would take 7,000,000,000 of them to make a teaspoonful of water. . . . Not only may fogs be produced by the drifting of warm humid air over cold surfaces, and by the importation of cold air over warm water, but also, however and wherever formed, they themselves may be transported by gently moving air to other places, even in many cases to localities at which fog seldom is generated in situ. Such advection, or drift, fogs are exceptionally frequent just inland from midlatitude seacoasts along which the prevailing wind is onshore." * Wherever cold air strikes a warmer ocean current, fogs accumulate. The Gulf Stream is responsible for fogginess in the British Isles; and the warm Japan Current for the Aleutian Islands' being rated among the foggiest places on earth. Despite their reputation, in the past 40 years the British Isles have had an average of only 34 days of fog and 198 of precipitation, compared with 200 days of fog and 60 to 80 of precipitation for the Aleutians since 1879.

* *Ways of the Weather* (Lancaster, Pa.: The Jacques Cattell Press), 1942, pp. 172-5.

MIST: As defined by the International Meteorological Conference, mist is a very thin fog, in which the horizontal visibility is greater than 1 kilometer, or approximately 1,100 yards. The United States Weather Bureau often uses the word mist as synonymous with drizzle or fine rain. Both mist and fog normally consist of minute droplets of water suspended in the atmosphere at or near the earth.

VISIBILITY

Visibility, or the transparency and illumination of the atmosphere as affecting the mean greatest distance toward the horizon at which mountains and prominent objects can be clearly recognized, is explained in terms of the greatest distance at which an object can be seen and the clarity with which its details can be distinguished by the normal eye. It is usually expressed on a numerical scale of visibility, which from time to time has been changed by the International Meteorological Committee.

Horizontal visibility, or visibility on the surface, is distinguished from vertical visibility, or visibility from the air. Surface visibility may be good when visibility from the air is poor, and vice versa. Clouds constitute the principal obstacle to vertical visibility.*

VISIBILITY SCALES: Horizontal visibility is observed and reported in the United States according to the following table:

VISIBILITY SCALE I

Scale	Descriptive Terms	Limiting Distance	
0	Dense fog †	Objects not visible at	50 yards
1	Thick fog	" " " "	200 yards
2	Fog	" " " "	500 yards
3	Moderate fog	" " " "	½ nautical mile
4	Thin fog	" " " "	1 nautical mile
5	Poor visibility	" " " "	2 nautical miles
6	Moderate visibility	" " " "	5 nautical miles
7	Good visibility	" " " "	10 nautical miles
8	Very good visibility	" " " "	30 nautical miles
9	Excellent visibility	Objects visible at more than 30 nautical miles	

* R. M. Paulter, "Visibility Observations." In *Quarterly Journal of the Royal Meteorological Society*, 63, No. 268 (January 1937), 31-47.

† *Radiation fog*, caused by radiation from the earth's surface, rarely exceeds 500 feet in height and clears soon after sunrise. *Advection fog*, caused by the transportation of warm moist air over a cold surface, may extend to a height in excess of 5,000 feet.

Visibility and corresponding weather phenomena are expressed in the United States weather code as follows:

VISIBILITY SCALE II

Visibility	Weather
1/5 mile or less	Heavy snow, dense fog
3/4 mile or less	Heavy mist
1/5 to 3/4 mile	Moderate snow, moderate fog
Over 3/4 mile	Light mist, light snow, light fog
Less than 1 mile	Thick blowing snow (blizzard)
	Thick blowing dust (dust storm)
	Thick blowing sand (sand storm)
	Thick smoke, thick haze
1/6 mile	Blowing dust, blowing sand, blowing snow

VISIBILITY AT NIGHT: The distances at which lights of certain specified candlepowers can be seen determine visibility at night.*

Since the latter fog cannot clear until the atmosphere becomes sufficiently heated to contain this added moisture, it may linger for several days. In spring and summer when warm air from the continents circulates over cold water, it is prevalent at sea. Here we have the carrying of warm moist air over a colder region where it becomes chilled below the dew point. On the other hand, as often happens in the United States in winter, a warm moist wind blowing inland from the sea encounters a cold surface and a fog is formed.

* For details see Ernest Gold, "A Practical Method of Determining the Visibility Number 'V' at Night." In *Quarterly Journal of the Royal Meteorological Society,* 65, No. 280 (April 1939), 139-64.

Photo by F. Ellerman; Courtesy, U. S. Weather Burea

CUMULUS FORMING FROM FOG. This unusual photograph, taken from Mt. Wilson Observatory, looks over the top of a fog-filled valley, where the fog is changing into cumulus clouds. Such walled-in valleys are favorite breeding grounds for radiation fog, which begins at or near the surface and gradually works upward to fill the valley.

Fogs are classified according to the way in which they are formed. Radiation fog, commonly called "land fog" or "summer fog," is formed by the simple cooling to the dew point of air already on the spot. To form advection fog, "drift fog," warm, moist air must be transported over a cold surface—or, more rarely, cold air over a warm surface. The third and rarest type, frontal fog, forms in front of an advancing cold or warm air mass.

Photo by W. J. Humphreys; Courtesy, U. S. Weather Bureau

ADVECTION FOG. This bank of low sea fog rolling over the surface of the ocean was photographed from a ship. Advection fog reaches a height of 1,200 to 2,500 feet.

Photo by F. Ellerman; Courtesy, U. S. Weather Bureau

VALLEY FOG, as seen from Mt. Wilson Observatory, California. Cirrostratus is seen above the screening layer of fog. This means good flying weather aloft, but bad for landing.

CHAPTER IX

WEATHER SIGNS AND OPTICAL APPEARANCES

For the most part weather signs are based on century-long observations by those whose interests have led them to observe weather changes closely. Many of them, however, including the more popular ones, consist of a mass of superstitions strangely preserved and transmitted. Though many are world-wide in their application, weather proverbs are usually of local application only, and must be so regarded. When local, in order to appreciate them, one must be acquainted with local conditions. Not infrequently weather indications give warning of the coming weather earlier than the barometer.

WEATHER SIGNS AND PROVERBS

DAME NATURE:

"In Spring she's an infant in swaddling green,
Her moods are angelic and always serene.

"In Summer she's feminine, sensuous, gay,
And flaunts her fine feathers to charm when she may.

"In Autumn her wrinkles instill her with rage,
She paints and she rouges to cover her age.

"In Winter she comes to the end of her fight,
And dreams peaceful dreams in a chamber of white.*

1. "Rain before seven, Shine before eleven." (This applies to light rains, not heavy storms.)

2. "When the sun is in his house, it will rain soon." (This adage of the Zuni Indians means that the ring around the sun or moon is a portent of stormy weather, winter or summer.)

3. "The bigger the ring, the nearer the wet."

4. "Clear moon, frost soon."

* Russell Wragg, in *The Singing Hearth.*

5. "The moon and the weather
May change together,
But a change in the moon
Does not change the weather." (A meteorologist's doggerel.)

6. "When Sirius rising with the sun, Marks the dog days well begun . . ." (This proverb refers to Sirius, the Dog Star, rising with the sun about July 23, midway of the 40-day period of the Dog Days, which begin July 3 and end August 11.)

7. "If Candlemas be fair and clear, There'll be two winters in the year." (Candlemas is February 2. Out of this traditional belief has grown the fictitious legend of the groundhog.)

SKY SIGNS INDICATIVE OF THE LOCAL WEATHER OUTLOOK: In regions where strong local influences, such as mountain barriers and large bodies of water, do not apply, local forecasting may be made with reasonable accuracy from the following sky signs:

1. The higher the clouds, the finer the weather.
2. Red at night—fair weather.
3. Red, lurid sky in the morning—bad weather with probable rain or snow.
4. Gray sky in the morning—fair weather.
5. Bright yellow sunset—wind.
6. Light, bright blue sky—fair weather.
7. Pale yellow sunset—rain.
8. Cirrus clouds thickening into heavier forms in rapid succession—stormy weather.
9. Rapidly moving cirrus clouds, particularly from the southwest—close proximity of a storm.
10. Stationary or slowly moving cirrus clouds—fair weather for at least 24 hours.
11. Stratus clouds moving from the south in the morning—a rapid rise in temperature.
12. Cumulonimbus clouds always indicate the probability of a thunderstorm.
13. "Whene'er the clouds do weave, 'Twill storm before they leave."
14. "Mackerel scales and mare's-tails, Make lofty ships carry low sails."
15. "Rain long foretold, long last. Short notice, soon past."

SKY SIGNS AT SEA—TO THE NAVIGATOR AND MARINER: 1. A dark and gloomy sky is an indication of strong wind; and if the clouds are hard and ragged-looking, strong gales may be expected.

2. Soft, downy, delicate clouds and a light blue sky indicate fine weather with light variable winds.

3. A clear pale or gray sky at sunrise indicates fair weather.

4. A clear yellow sunset indicates strong breeze.

5. A pale sky and sunset in a bank of clouds is an indication of easterly wind.

6. A red sunrise with a red sky is an indication of bad weather with east or northeasterly winds.

7. A clear sunset with a red sky is an indication of fine weather and probable westerly winds.

DEW SIGNS:

"When the grass is dry at morning light
Look for rain before the night.
When the dew is on the grass
Rain will never come to pass."

"When the moon is dry
The rain is nigh.
When the moon is wet
No rain you get."

OPTICAL APPEARANCES

SUNSET COLORS: A lowering gray sunset, or one where the sky is green or yellowish green, may indicate rain. A red sunset with clouds lowering later in the morning may also indicate rain.

"Evening red and morning gray
Sets the traveler on his way.
Evening gray and morning red
Sends down showers on his head."

"Sky red in the morning
Is the sailor's sure warning.
Sky red at night
Is the sailor's delight."

SKY COLOR: A deep blue of the sky, even when seen through clouds, may indicate fair weather; on the other hand, a growing whiteness of the sky may foretell an approaching storm.

ZODIACAL LIGHT: Zodiacal light is a cone of faint light in the sky which is sunlight stretching along the Zodiac from the western horizon after the twilight of sunset has faded and from the eastern horizon before the twilight of sunrise has begun.

CORONA: The small colored circle frequently seen around the sun or moon is called a corona. One growing smaller indicates rain; one growing larger indicates fair weather.

With or without shadows, the presence of a corona, or iridescent colors near the sun or moon, distinguish small altocumulus from cirrocumulus clouds. When the sun or moon is seen through fragments of cumulonimbus, it is often closely surrounded by a corona appearing as a brilliant glow. Observed usually when a light mist is floating in the air, coronas are formed by reflection from the external surface of globules of vapor.

Fractocumulus clouds produce complete coronas or segments of arcs, according to the extent of the fragments which traverse the lunar disk. These coronas are also prismatic, having a blue internal tint.

HALO: A halo is a large circle or arcs of circles about the sun or moon, produced by the refraction, or sometimes reflection, of the light by ice crystals in suspension in the air.* A halo after fine weather indicates a storm, although on the whole, halos and coronas are poor indicators of coming weather changes. Rings around the moon show that some place in the air, between us and the sun or moon, is floating a thin layer of mist or cloud, the water drops of which are about equal in size.

Water droplets and ice crystals, common objects in the upper air, are responsible for an extensive group of optical phenomena classified under the generic name halo. Especially in high latitudes, floating ice crystals at ground level may be the cause of halos. The most common is the halo of 22°—that is, 22° radius—surrounding the sun or moon. On rare occasions cirrus gives rise to a large solar and lunar halo of 22°. When the halo is produced by the sun—solar halo—it sometimes presents the seven colors of the spectrum, although usually it has only a single internal tint of orange, at times terminatnig in a little red. The great halo produced by the moon—lunar halo—on the contrary is almost always white and seldom exhibits the tint of orange without the red.

The halo of 46° and the rare halo of 90°, called halos of Hevelius,

* It is not possible to explain refraction phenomena, such as the deviation of rays through water drops, without going extensively into atmospheric optics. Elaborate discussions of these light phenomena are found in W. J. Humphreys, *Physics of the Air;* Exner, *Meteorologische Optik;* and Mascart, *Traité d'Optique.*

also surround the luminary.* Additional forms of halo are the tangent arcs, the parhelic (or paraselenic) circle, and anthelia.

A sheet of high altostratus is distinguished from a somewhat similar sheet of cirrostratus by the convention that halo phenomena are not seen in altostratus. The thin white veil of cirrostratus does not blur the outlines of the sun or moon and gives rise to halos.

Halos and coronas are more common than most people think. For instance, the United States Weather Bureau reported three solar and two lunar halos in the one month of January 1942. Halos are common and brilliant in the polar regions.

Reports from many parts of the British Isles on April 19, 1937, reveal a complex distribution of halo phenomena, including the halo of 22° and 46° mock suns, mock sun ring, and arcs of contact. The halo, first appearing at Dublin at 6 h. 35 m. G. M. T., included two brilliant mock sun rings and a sun pillar. Oxford, Torquay, and Paignton subsequently reported simple halos. Before noon, halos of 22° appeared in Lancashire, Cheshire, and west Yorkshire, traveling southeast, the last record being at Lympne Kent at 15 h. 40 m. At Aberdeen and Leuchars, north of the main area of development, halos were reported at 12 h. Lunar halos were observed at Oxford at 21 h. and at Cramwell at 21 h. 20 m. on the same day.

The halo complex seems to have been associated during the day with a warm front which moved slowly eastward across Ireland. Heralding the warm front, cirrus was observed. Nephoscope measurements gave wind speeds of 40 mph from WNW and NW at Renfrew at 7 h.; 55 mph from between NW and NNW at Boscombe Down, Wilts, at 10 h.; and 65 mph from WNW at Calshot at 16 h.†

PARHELIC CIRCLE: A halo or circle of white light passing through the sun and around the sky, equidistant at all points from the zenith, and consequently parallel to the horizon is called the parhelic circle. It shows no color separation, and, inasmuch as it passes through the source of illumination, cannot be due to refraction.

MOCK SUN (SUN DOG): At different points on the parhelic circle appear several bright spots known as parhelia, of which the most commonly seen are the mock suns, or sun dogs. They occur near the

* Humphreys ascribes the formation of the 90° halo to the refraction and internal reflection of the sun's light by bipyramidal ice crystals. *Physics of the Air* (New York: McGraw-Hill Book Co.), 1940, pp. 462-82.

† C. E. P. Brooks, "The Halo Complex of April 19, 1937." In *Quarterly Journal of the Royal Meteorological Society,* 63, No. 271 (July 1937), 416-8.

intersection of the 22° halo with the parhelic circle. Analogous phenomena in connection with the moon are called paraselenae, or moon dogs.

One need only see a mock sun in cirrostratus to realize how much more apt is the name "mock sun" than the international name, "parhelion." It is related of Sir Gilbert Walker, the eminent meteorologist, that he once pointed out to his fellow traveler a mock sun, seen while they were crossing the Crast' Aguzza at Pontresina. His companion insisted that it must be the real sun, and was only convinced when Sir Gilbert showed him the real sun on the other side of the ridge.

From Kent, England, comes an account of the appearance of a mock sun in a vapor-trail cloud. On December 22, 1942, some fifty airplanes were flying northeast at a considerable altitude, most of them making vapor trails. In the words of an observer:

> By 13.19 h., G. M. T., these "trails" had coalesced and formed two long clouds of indeterminate structure. A minute later I was delighted to observe a mock sun forming on the underside of the longer cloud. This phenomenon of a faint red color, lasted until 13.25 h., by which time the cloud had all drifted "above" the sun.*

Like halos, mock suns as a rule are forerunners of stormy weather; and at one time they were thought to presage dreadful events. In the early part of 1924 a remarkable phenomenon caused great alarm in Sweden. Four mock suns appeared, the uppermost surrounded by a cross with diagonal rays, which was heralded as a divine portent.

Mock suns are rare in the British Isles, but an excellent specimen was seen at Aldershot, Hants, on May 14, 1940, at 19 h. 3 m. It lasted some 20 minutes, and during part of the time the colors—red nearest the sun—were visible. The sun was then 4° above the horizon, and therefore the distance between sun and mock sun would be 22°, as is usually the case when the sun is low.† Sun pillars and mock suns below the observer have been seen in the British Isles from a height of only 1,300 meters (4,264 feet).

ANTHELION: An anthelion is a single bright, ill-defined spot of white light on the parhelic circle opposite the sun. It is seen on rare occasions. Its formation has been attributed to the double internal re-

* D. S. Hancock, "A Mock Sun in a Vapor-trail Cloud." In *Quarterly Journal of the Royal Meteorological Society,* 69, No. 298 (January 1943), 46.

† The *Quarterly Journal of the Royal Meteorological Society* for July 1940 has an excellent photograph of this mock sun, p. 279. For further information on mock suns, see F. J. Whipple, "How Mock Suns Are Produced," in the same issue.

flection of sunlight from surfaces that make an angle of 90° with each other, the light entering and leaving through the same surface.

RAINBOWS: A rainbow is evident during a rain because the white light of the sun is broken up into various colored rays as it passes through the raindrops, just as a prism breaks a white light into various colors. The raindrops act exactly as does a prism. In other words, this luminous arch is formed by the refraction and reflection of light in drops of water. Consequently, whenever this optical phenomenon occurs, three circumstances will be observed in connection with its appearance: (1) drops of water must be present; (2) the sun must be shining; (3) the observer must be between the sun and the water.

Refracted as they enter the drops, the rays are reflected from their posterior surfaces. In addition, they are refracted as they re-enter the air, the colors being separated by their unequal refrangibility.

One usually observes a rainbow on the opposite side of the sky from the sun. When two appear, it is the brighter one that is the primary rainbow, and the dimmer is the secondary. In the primary rainbow the red invariably is on the outside and the violet on the inside. In the secondary rainbow the colors are reversed—the violet is on the outside and the red on the inside. Two rainbows are the most the ordinary observer sees, but there are more rainbows and supernumerary ones. The third and fourth bows are between the observer and the sun, hence difficult to see; the fifth is above the secondary and so dim it can seldom be discerned.

From a historical point of view the most valuable of the earlier contributions to scientific explanations of the rainbow is a treatise by Marco Antonio de Dominis (1566-1624) in which it is shown how the primary bow is formed by two refractions and one reflection, and the secondary bow by two refractions and two reflections. The first of the ancient observers to attribute this phenomenon to refraction was Vitellio. Theodoric of Vrieberg, a scholarly Dominican, elaborated on the idea in explanations made public between 1304 and 1311.

RAINBOW AT MIDNIGHT: A rainbow at midnight is an unusual phenomenon of compelling beauty. I recall seeing one in Texas on a late spring night between eleven o'clock and midnight. The heavens overhead and in the west were darkened by a black cloud, and a slow drizzling rain was falling. The moon rose bright and clear in the east, and presently a light streak could be seen in the west, reaching up from the horizon halfway to the zenith and turning toward the north as the moon rose higher. The peculiar streak in the west lengthened out and was met by a similar streak extending its curve toward the south; and there at about midnight, plainly defined on the black cloud in the west, was a complete rainbow. Moreover, the dim outline of a second bow could also be traced. The gorgeous phenomenon lasted about ten minutes and then disappeared.

CIRCULAR RAINBOWS: On a small scale completely circular rainbows can be seen in the spray from a waterfall. In an airplane high enough so that the rainbow cone would not be intersected by the land below, an aviator could observe a rainbow completely circular. In the middle of such a rainbow would be found a shadow—the shadow of the observer and his airplane.

GREEN AT SUNSET: Another effect due to the refraction and reflection of light as it passes from denser to rarer strata of air is present when the upper edge of the setting sun turns a vivid green just before it disappears.

FOGBOW: A rainbow, faintly colored, formed in a fog, is called a fogbow. The outer margin is red, the inner blue.

MIRAGES: Mirages are misleading appearances due to abnormal refraction of solar rays across strata of air of unequal density. Distant objects appear deformed, magnified, multiplied, transported to a certain distance, raised, brought nearer to the eye than the object, or inverted and reflected, according to the deviation which the abnormal density of the air causes in the luminous rays. The mirage is sometimes visible upon the surface of the sea or lakes and large streams; sometimes upon dry and sandy plains; sometimes upon highroads or the seashore. It is most frequent in arid plains, where the soil, exposed to the burning rays of the sun, becomes intensely heated; hence the strata of air near the ground are rapidly heated and so are less dense than those above.

In this case rays of light passing from any distant object, as a tree, to the ground, are refracted more and more toward the horizontal, until finally they are reflected from a horizontal layer of the heated air and reach the eye from beneath. Then an image of the object is seen as if mirrored in the tranquil waters of a lake.

Mirage is thus an apparent displacement or distortion of observed objects by abnormal atmospheric refraction, and to such an extent that sometimes objects are seen double, being repeated laterally instead of vertically. Again, images of distant objects are seen reflected beneath or suspended in the heavens above.

From their ship in the Antarctic, the members of one of Shackleton's expeditions saw the sun set one afternoon, then rise clear of the horizon, and a few minutes later set again. This unusual spectacle was an effect of mirage.

Polar mirage presents an image as high as three-quarters of a mile from the earth's surface. An expedition at Mount Evans, Greenland, with a tested horizon visibility of only a dozen miles, experienced just such an illusion. On certain days wholly new panoramas would unfold before their eyes; glaciers far below the horizon and far-distant landscapes would be clearly visible.

Desert mirages reflect nearer objects which are visible at low altitudes.

FROST SMOKE: In the polar regions turbulence is reflected in what the northern sealers and Antarctic whalers know as "frost smoke" or "Arctic sea smoke," a curling mist caused by contact of very cold air with warmer water. When the cold air, much below freezing, blows over the open sea, it looks like a hot-water bath with steam rising from the surface. This "steam fog" is composed of crystals formed by horizontal mixing and resultant condensation when the cold air and warmer water meet. It is one of the most beautiful sights of the polar seas and may last for days until dispersed by a breeze.

When the sun is low on the horizon and lily pads of ice form on the water, the sea seems to smoke, and vapor drifts lazily over its surface, to spiral and respiral in twisting columns to a great height. Just then, at a specific point, seemingly determined by the temperature of the air, the smoke is cut off abruptly, and the clipped-off tops of the columns wave and writhe in the air, shutting off a great silent land of ice from an outside world of movement and life.

Before the sun comes up in the Antarctic spring, the frost smoke forms appear at the edge of the continental ice along the sea front. From below the horizon the first rays of the sun transform the tall smoke columns into a soft, delicate pink. Between the smoke screen and the sun, huge cakes of drifting ice loom like distant mountains. In the fall the sea smoke spells warning that tiny disks of ice are gathering fast and soon the waters of the polar depths will lie beneath a solid surface of ice.

TWILIGHT: Twilight, or light scattered by the air, is an indication of the presence of gas molecules at immense heights above the surface of the earth. Its highest layers produce visible reflections at about 37 miles. Essentially twilight is nothing but light reflected from the extreme upper layers of air illuminated by the sun after it is below the horizon of the observer.

ASTRONOMICAL TWILIGHT: This is the interval between sunrise or sunset and the total darkness of night.

CIVIL TWILIGHT: The period of time before sunrise and after sunset during which there is enough daylight for ordinary outdoor occupations.

ANTITWILIGHT ARCH: This term applies to the pink or purplish zone of illumination bordering the shadow of the earth (dark segment), in the part of the sky opposite the sun after sunset and before sunrise.

BANNERS OF THE SKY—AURORA POLARIS: Confined to the thin air of high altitudes and appearing as bands, waves, or streaks of pale light, the Aurora is a luminous phenomenon, in effect an electrical discharge in the high atmosphere, and is observed mostly in sub-Arctic and sub-Antarctic latitudes. Together with other phenomena it proves the existence of gas molecules at great heights. In the Northern Hemisphere it is called Aurora borealis; in the Southern Hemisphere, Aurora australis.

Nature's supreme spectacle of the long night, the Aurora is visible near the poles, lighting up the sky and centering about the magnetic meridian. It forms an arch or ring of colored light over the magnetic pole at a great height in the atmosphere, from 50 to 200 miles. One seen in Norway in 1926 extended unexpectedly to 600 miles. Consequently, the Aurora is believed to consist of electrical discharges occurring in a gas of very low density in the very thin air high above the polar regions, where thunderstorms are practically unknown. The most common form is that of a luminous arch, the summit of which is in the magnetic meridian of the place of obser-

Figure 4.—Diagram Showing Heights of Various Phenomena (After Dobson) *

* By permission of the Carnegie Institution, Washington, D. C.

vation, and from which vivid flashes of light dart toward the zenith. Colored fringes and streamers shoot out from the arch in all directions, sometimes spreading over the whole sky, then shrinking back with a pulsating motion.

The zone of greatest auroral display is the North Axial Pole. In our hemisphere it is most frequent at about Latitude 60° over North America and the Atlantic Ocean, and near 70° in Siberia. It is rare near the Equator. In this connection it is perhaps well to observe the distinction between the North Magnetic Pole and the point on the earth where the magnetic axis meets the surface. It is the distance from the magnetic axis of the earth that counts, and that axis meets the surface of the earth about midway between the North Magnetic Pole and the North Pole. This point is near northwestern Greenland, and it might be named the North Axial Pole. The zone or belt of greatest auroral display has this point for center on the earth. Nevertheless, observations with the spectroscope point to a faint "permanent Aurora" as a normal characteristic of the sky in all parts of the world.

According to Dr. Carl Störmer, sunlight would seem to exert a pressure sufficiently powerful and in such a manner as to cause the earth's atmosphere to protrude far out into space, somewhat like the tail of a comet.* The sunlight Aurora rays peculiar to this tail—estimated at 2,500 kilometers (about 1,550 miles) from the earth, reckoning from the point of sunset—do not descend beyond the line of demarcation that distinguishes the sunlit from the dark atmosphere. As evidenced from the parallax obtained against a common background of stars, Aurora rays occur with the usual night altitude from 100 to 600 kilometers (about 62 to 372 miles), and have been so observed by photographic means. Measures of meteor trails not only reveal the pressure of air at a height of 190 to 200 miles, but demonstrate the fact that even at that immense altitude in relation to our atmosphere the air must be dense enough for the heat caused by the friction of a rapidly moving body to emit light.

It is believed by many that the Aurora does not cause the swishing or rustling sounds frequently attributed to it. The 60 to 70-mile-high atmosphere where it surges and flares is so rare as to be a fairly high vacuum; and sound cannot exist or travel in a vacuum. Consequently, it is physically impossible for the Northern Lights as such to make the eerie swishing sound reported by many an Arctic explorer. The noises heard and frequently reported are perhaps due to electrical dis-

* *Nature*, February 16, 1929.

turbances such as brush discharges occurring on the earth's surface near the observer, who fails to notice them because the fascinating Aurora display is engaging all his attention.

In the final analysis, it may be that on occasions the Aurora—the loftiest visible feature of the earth's atmosphere—glows with greater intensity because a few spots, terrific hurricanes of incandescent gas, appear on the sun. Electrical particles flash across an abyss of 93,000,000 miles and strike the earth's rarefied upper air. The northern sky is aglow with an Aurora, seen as far south as Florida, but rarely in the tropics. A display of Aurora was seen in New York on September 18, 1941.

In other words, while the magnetic field of the earth affects the behavior of the Aurora, the presence of sun spots, or one immense sun spot squarely facing the earth, would seem to augment its activity. Apparently auroral displays are most numerous when the sun has its maximum number of spots. The 11-year period of the sun spots applies to the Aurora. Certainly there would seem to be a close connection between auroral displays and magnetic and solar activity.*

When an enlarged view of a sun spot is studied and the light from it analyzed, the dark interior center is seen surrounded by a turbulent area. Whirling masses of gas are observed arranging themselves in vortices. In the years when sun spots are most numerous, magnetic disturbances are most frequent and appear with marked intensity. There is thus every indication that a sun spot is in reality a terrific solar hurricane similar in formation to the tropical hurricanes that originate in the West Indies and sweep north to northeastward.

Nitrogen and rarefied oxygen are indicated in the lines of the spectrum of light from the Aurora. The light would appear to be emitted by a rarefied gas through which an electrical discharge is passing.

The Aurora has many forms, depending upon the latitude in which it is observed. Most common are arcs and rays; in high latitudes corona effects with surrounding curtains and draperies may be seen. Sometimes the Aurora is stationary; sometimes there is a rapid cross-motion, or the rays seem to shoot rapidly toward the zenith, each beam or streamer varying in brightness and fading away to give place to another.

When the Aurora is faint, it is usually white; if it is fairly bright, yellow predominates; if it is very bright, other colors, particularly red

* See *Quarterly Journal of the Royal Meteorological Society*, 66, No. 283 (January 1940), 80-1. Three auroral displays seen at Merseyside in 1939 are described, followed by notes on the accompanying magnetic activity, written by the Astronomer Royal, Sir H. Spencer Jones.

and green, will be seen. The seething nebulous luminescence may give the appearance of a sea of breaking waves, rose-pink to red, especially the crests of the waves, with flashes of brilliant green between them. Or clusters of beams may form vast sweeping draperies, and the whole sky be filled with gorgeously colored fire—yellow, green, pink, and crimson.

Optical illusions tend to increase when the moon is above the horizon, and Auroras described as low are often due simply to the light of the moon. Mists and clouds lit up by moonlight have about the same degree of brightness as the Aurora, and portions of halos can hardly be distinguished from auroral streamers. Faint Auroras cannot be seen in twilight or anywhere near a bright moon.

NACREOUS CLOUDS: According to the investigations of Störmer, nacreous clouds exist in the stratosphere at heights of about 20 to 30 kilometers or some 12 to 18 miles. Characterized by intensive prismatic colors like mother-of-pearl, such clouds are comparatively easy to distinguish in the sky. They appear with certain weather conditions in winter, namely, on the border of a great cyclone where ascending air masses creates a Foehn wind, or Chinook. Fine and almost clear weather make it possible to see these clouds at great heights in their brilliant, many-colored setting. They may remain luminous two or three hours after sunset, and may be observed as illuminated even by moonlight. The best time to photograph them is therefore in the early morning before sunrise, or late in the evening after sunset, while the stars are visible.

In observing nacreous clouds, it is important to note their magnitude and dimensions in degrees, their colors at different parts of the cloud sheets, and all changes occurring, and also their position in relation to the sun and stars. The direction and velocity of the clouds should be carefully noted. These clouds should not be confused with other iridescent effects among clouds at medium altitudes.

Their silver to orange color is due to diffraction. The iridescent masses of these clouds, peculiar to the stratosphere, have been observed in latitudes 60° to 70° N., floating 14 to 17 miles above the earth, or at two to three times the elevation of cirrus. Their altitude was determined by Störmer at an observatory station near Oslo, Norway, by taking simultaneous photographs against a starry background from two or more observatories and measuring the relative displacement in the pictures, the same method adopted to fix the height of Northern Light displays.

NOCTILUCENT CLOUDS: Observed during the summer nights, these clouds, unlike the mother-of-pearl, are bluish white, not iridescent; and they are believed to be dust clouds floating at least 50 miles above the earth, or even at much greater altitudes, shining with reflected light. Although no definite information exists as to their origin and content, one theory is that they may be caused by meteors—the myriads of meteoric fragments that hourly enter the atmosphere, ground to the finest powder by the friction of the air. The earth pulls to itself daily millions of meteors, mostly about the size of peas or small pebbles. The largest of them become visible as shooting stars when they hit the atmosphere, and dart across the sky at some 26 to 100 miles a second. Scores of comets have disintegrated either wholly or in part into meteors. Dust is strewn along the orbit of the comet, and when the earth crosses that orbit, the dust is caught by our atmosphere.

Sometimes noctilucent clouds are visible throughout the short nights of summer and resemble luminous cirrus clouds; but not all the clouds at this immense altitude are lucent. Noctilucent clouds were seen during several summers after the eruption of Krakatoa in 1883, an eruption corresponding in violence to the volcanic explosions of Asama in 1783 and of Katmai in 1912, when pulverized rock was blown far above the levels of the highest clouds. Noctilucent clouds are occasionally still reported.

IRIDESCENT CLOUDS: The distinguishing feature of iridescent clouds is irregular patches or fringes of iridescence. Such iridescence, however, should not be confused with the delicate pinks and greens peculiar to the finest mother-of-pearl; nor do iridescent clouds correspond in location with the ordinary corona or forms of halo such as parhelia.

Iridescent effects observed in clouds of the lower medium—clouds which consist of water droplets and not of ice crystals—are probably fragments of coronas of unusual size produced by exceedingly fine cloud particles. When altocumulus are about 20° to 30° from the sun and in the process of evaporating slowly, they frequently display iridescent red and blue, which may be repeated more than once.

The distinction is based upon the fact that, while crystals are responsible for the numerous forms of the halo, droplets produce rainbows, coronas, and iridescence.

LIGHTNING: The conditions which give rise to electrical excitement in the atmosphere are much more intense in warm than in cold latitudes; hence the thunderstorms of the tropical regions greatly exceed, in both frequency and violence, those of temperate and cold climates.

Lightning is the dazzling light produced by an electrical discharge passing between clouds or parts of clouds which are oppositely electrified. A lightning stroke first strikes downward to earth as a faint "leader discharge," and then moves back to the clouds, the visible part of the flash being the upward stroke.

Lightning flashes are distinguished as streak or chain lightning, sheet, ball, and beaded lightning.

Streak lightning has the aspect of a sharply defined chain of fire and moves at many thousand miles per second. Its irregular course is attributed to the variations in the resistance of the air, which is sufficient to turn it aside frequently in the direction of less resistance.

Sheet lightning includes the expanded flashes which occur during a storm and the heat lightning seen on summer nights when no clouds are visible, which is supposed to be the reflection of a storm taking place below the horizon.

Ball lightning is seen on rare occasions, when the electrical discharge takes the form of a ball of fire, and, descending with less rapidity, is visible for several seconds. Beaded lightning is very rare.

Over 90 per cent of the lightning strikes on commercial aircraft over the United States have taken place when the airplane was flying in cumulus, or thunderstorm, clouds amid precipitation and at an air temperature within 6 degrees either side of freezing. The majority of these strikes have been at night and preceded by St. Elmo's Fire; and began when precipitation was encountered within the cloud. Turbulence generally increased, and the discharge followed. The area of turbulence was largely at the boundary surfaces between vertical currents. The strongest vertical currents were found to occur where turbulence was greatest—namely, at levels between 10,000 and 20,000 feet at the time of maximum vertical motion.

Good visual indication of the presence of turbulence is the scud roll, or roll cloud, appearing near the leading edge of the base of a typical thunderstorm. Not only does it point to the existence of an eddy between the steady updraft and the downdraft immediately behind, but also to the probability that similar current eddies may lurk between vertical currents within the cloud and also in the clear air below the cloud.

During a thunderstorm one should avoid proximity to a wire fence. A wire struck at any point becomes dangerous throughout its length, and a lightning flash striking a fence may well prove fatal to someone who touches it a mile away. Nevertheless if the radio aerial is rolled up, lightning is not a serious hazard to all-metal aircraft.

Off-season lightning accompanying snowstorms often gives rise to amusing misunderstandings. The latest was on the evening of January 15, 1944, when a heavy fall of snow began at eight o'clock and lasted all night, enshrouding the city of New York. In the midst of the storm two loud peals of thunder were heard seaward, the first at 10:42 p.m., the second at 10:46. Police headquarters, fire headquarters, newspapers, and the Navy all received inquiries about the "explosion offshore" before the Weather Bureau in the Whitehall Building, where the thunderclaps were plainly heard, settled the matter. A similar experience two years earlier had apparently been forgotten. At 3:30 a.m. on January 26, 1942, residents of the Bronx had called up the Police Department to find out what the shooting was about.

ST. ELMO'S FIRE: In certain conditions of the atmosphere, globes or spires of electrical light, called St. Elmo's Fire, are seen tipping the extremities of tall, pointed objects in contact with the earth, such as church spires or masts of ships, lightning rods, steeples, etc. St. Elmo's Fire is a luminous brush discharge of electricity, also called "corposant." In his "Golden Legend" Longfellow notes its weather significance:

> Last night I saw St. Elmo's stars,
>   With their glittering lanterns all at play
> On the tops of the masts and the tips of the spars,
>   And I knew we should have foul weather today.

Characteristic of the disturbed electric conditions associated with thunderstorms, they are usually accompanied by a hissing or crackling noise. Next to lightning, the appearance of these strange violet-colored glows of fire was perhaps one of the earliest observed manifestations of atmospheric electricity.

BROCKEN-BOW, OR "GLORY": SPECTER OF THE BROCKEN: The shadow of an observer and of objects in his immediate vicinity cast upon a cloud or fog bank is the "specter of the Brocken," named for the highest peak in the Hartz Mountains, from the summit of which the phenomenon can be seen perhaps a dozen times a year—it is more common at numerous other high places throughout the world. Sometimes the shadow is accompanied by a series of concentric colored rings, called the "glory" or brocken-bow. In western China is a mountain called

"Gin Din"—"golden summit"—where the shadow is popularly identified with Buddha, and the colored circles above its head are called "Buddha's glory."

The aviator of today who sees the shadow of his plane cast upon the clouds, in many cases surrounded by a ring of colored light, is looking upon a modern variety of the "specter of the Brocken." On a transatlantic flight in June 1928, Amelia Earhart, Gordon, and Stultz had such an experience.

Provided there is a layer of cloud in a suitable position to receive the shadow, an aviator may see the specter at any time of day when the sun is above the horizon. Sometimes this weird phantom of misty mountaintops may be seen at lower levels, as on a fog bank at sea or in foggy weather by the artificial lights of towns. The phenomenon is visible from a mountaintop only when the sun is low on one side of the mountain, and a wall of mist rises like an immense curtain near the observer on the opposite side. If the mist consists of fine drops of about uniform size, a series of rainbow-tinted rings may be seen encircling the shadow's head —the brocken-bow. In some instances a white fogbow is seen. In any case, the setting must always embrace mist and sun for the colored rings to be visible.

A similar phenomenon is known in the polar seas. Whenever a rather thick mist rises over the ocean, an observer placed on the mast of a ship may see one or several circles on the mist. These circles are concentric, and their common center is in a straight line joining the eye of the observer to the sun and extended from the sun toward the mist. The number of circles varies from one to five. They are particularly numerous and well colored when the sun is very brilliant and the mist thick and low.

COLOR AS AN OPTICAL PHENOMENON: Clouds illuminated by the setting sun are red, particularly on the side toward the sun. Near the summits of the clouds, where light from the sun has come through less air to reach the clouds, the red may turn to yellow. In numerous combinations of colors, some parts of the clouds may be brightened by scattered light and look gray.

The blueness of the sky is a measure of its transparency. According to a weather proverb, an intense blue in distant mountains presages rain. The presence of water vapor in the air increases the effect, as a distant landscape looks bluer when the relative humidity is high.

Since the line of sight is high up in the clear air, visibility is clearer from mountain to mountain than on the surface, where there is usually a haze to penetrate which obscures all detail. In India in cold weather it is possible to see the Himalayas up to 120 miles away.

The light blue of the sky is an atmospheric phenomenon. If the air were removed from above us, the sky would be black. In the balloon "Explorer II" at a height of about 13 miles, Colonel A. W. Stevens observed the sky to be very black with a mere trace of blue. Were it not for the luminosity of the sky, shadows from the light of the sun would be very dark. Yet if there were no dust particles in the air, selective scattering of the light by the molecules of the air would be enough to produce a blue color in the sky.

Blue moons are another optical phenomenon. Eight minutes after sunset—and, paradoxically, sunset is red for the same reason the sky is blue—a blue moon was seen at Santa Barbara, California, on September 15, 1934, at 6:15 p.m. The sky was spectrum blue; and the moon, at first quarter, seen through a magenta veil of cirrocumulus, was sky-blue. Blue and green moons were seen after the Krakatoa eruption.

Speaking of "blue moons," the "Magazine of the Province of Western Australia" for July 1936 quotes the following from Archdeacon Simpson:

> March 9th. There was another blue moon at Broome—a magnificent blue. It appears in the east after sunset with the nearly full moon above the horizon, and when the sunset turns the sky to scarlet the moon shows a vivid blue by contrast. That was the third within three months, so "once in a blue moon" means less here than in England.

Photo by Dr. G. A. Clarke; Courtesy, U. S. Weather Bureau

RAINBOW, PRIMARY, SECONDARY, AND SUPERNUMERARIES. The clouds behind the rainbow are heavy or swelling cumulus or cumulonimbus, and the ragged low clouds of bad weather. In regions where cyclonic storms move eastward, if a rainbow is seen in the morning a storm center is likely to be westward, and it will approach nearer. When a thunderstorm passes eastward in the late afternoon, a rainbow is usually seen on the west of it. The center of the bow will be directly opposite the sun, since the rainbow is formed by sunlight refracted by drops falling from the rear of the cloud.

The photograph above is a typical rainbow setting—the sky largely overspread by brightly illuminated cumuliform structures and a series of dark fractocumulus clouds. In the middle distance in such a setting may be seen a screen of falling rain. This type of sky is hazardous for aircraft because of severe turbulence and possible hail. Lightning also is common in this kind of cloud.

Courtesy, The Carnegie Institution, Washington, D. C.

AURORA BOREALIS. On clear moonless nights the Aurora may appear in the form of arcs, bands, rays, curtains, coronas, patches, or diffuse glows. The sky underneath the arced form looks dark and smoky; and two or more parallel arcs are frequently seen—as many as 9 in the polar regions. The photograph shows auroral bands, off the north coast of Siberia; Amundsen's "Maud" in the foreground.

Courtesy, U. S. Weather Bureau

NOCTILUCENT CLOUDS. Six views of noctilucent clouds, taken near midnight on July 10, 1932. Luminous, cirruslike, they are sometimes visible throughout the short nights of summer. Since they are lit up by the sun from below the horizon, they are seen, extremely high in the earth's atmosphere, after sunset or before sunrise. They were reported during several summers after the eruption of Krakatoa, and and are still occasionally observed.

Photo by C. Stormer; Courtesy, U. S. Weather Bureau

NACREOUS CLOUDS. Little is known about these strange high-flying dust clouds. They gleam with reflected light and show brilliant iridescence. It is supposed that they are dust clouds.

Courtesy, U. S. Weather Bureau

NOCTILUCENT CLOUDS. Another view of night-gleaming clouds, this one taken near midnight on July 27, 1909.

Photo by W. O. Solberg; Courtesy, General Electric Co

CLOUD-TO-CLOUD LIGHTNING STROKE. Judging from the streamer formation shown at the left-hand corner, this was probably a cloud-to-cloud stroke. Note the streamers toward the ground which did not develop into a cloud-to-ground stroke. The photograph was taken on August 1, 1939, at Lodgegrass, Montana. The distance from the camera was probably 2 to 3 miles. More discharges pass from cloud to cloud than from cloud to earth.

Most lightning is streak lightning, the familiar sinuous bolt. "Ball lightning" looks like a mass of fire moving deliberately, like a stalled thunderbolt, through the air or along the ground, and in most instances vanishes with a violent detonation. A luminous ball, about the size of a clenched fist, it may occur within buildings as well as out of doors. "Beaded lightning" is rare. As the name implies, it resembles a string of fiery beads. A reflected flash, known as "heat lightning," may be seen playing about the horizon without thunder being audible. "Sheet lightning," a diffuse glow over the sky, is the reflection of streak lightning hidden by clouds or below the horizon.

Sometimes a bolt splits into "forked lightning," an allusion to its appearance when divided into two or more branches.

Courtesy, U. S. Weather Bureau

STREAK LIGHTNING. This excellent example of streak lightning, photographed at Miami Beach, Florida, at 10 o'clock on a May night in 1942, shows the spectacular side of a discharge of atmospheric electricity. The "streak," or ordinary bolt of lightning, may be single; but as a rule a portion of it splits into smaller downward branches that may or may not reach the surface.

Photo by General Electric Co.

NATURAL LIGHTNING STROKE. This lightning stroke was photographed from the General Electric Lightning Observatory at Pittsfield, Massachusetts, during the storm of July 11, 1936, at approximately 3:20 a.m. (Enlargement made from ST-21.)

Photo by Arthur Ellis; Courtesy, Washington Post

BRANCHING LIGHTNING STROKE. Cloud-to-earth lightning discharges at the front of a thunderstorm over Washington, D. C. "If you heard the thunder, the lightning did not strike you. If you saw the lightning, it missed you; and if it did strike you, you would not have known it." (McEachron and Patrick, "Playing with Lightning," New York, 1940.)

Photo by General Electric Co.

LIGHTNING STROKE. A long-continuing discharge, terminating in a heavy-current peak. A part of the left-hand branch is cut off by the window at the beginning of the rotating image. Photograph taken on August 18, 1937, at 2:08 a.m., MSB-67. (Lens openings, still F. 16, Rot. F. 8, SS PAN film.)

Photo by General Electric Co.

MULTIPLE LIGHTNING STROKE. This stroke consists of long-continuing low-current discharge followed by 6 non-continuing discharges. The arrow indicates the point at which the oscillograph started to record. Photographed August 11, 1937, at 9:52 p.m., MSB-46. (Lens openings, still F. 15, Rot. F. 8, SS PAN film.)

CHAPTER X

VARIATIONS OF CLOUD COLOR

The chorus of clouds in the "Nephili" of Aristophanes still chants across the centuries:

> We are kin to the rivers, the streams and the pools;
> We master the wind and the swelling wave;
> Weeping, we furrow the well-tilled earth,
> Digging swift channels to the sea.

High in the sky or resting on earth, clouds are man's universal companion. In a sense every cloud is a fog lifted to varying heights by rising air and shaped by losing energy, caused chiefly by the winds. White mist, as in substance they are, clouds can cut off the sun as effectually as if they were solid matter. This is obvious to anyone who has watched a ragged drift, itself of inky blackness, trail across the glowing front of a broad-lit thundercloud, or seen the effect in reverse when a chain of ashy-white crests stands out startlingly clear against a distance of black-purple, glooming under the shadow of a rising storm. Perhaps no better example can be given than a layer of stratocumulus consisting of large lumpy masses or rolls of dull gray color with brighter interstices in the process of forming from degenerating cumulus with crepuscular rays.

Cloud color and shade depend upon the position of the cloud in relation to the sun and the observer. Of the wide range of colors, harmonizing or contrasting, which make the clouded sky the most magnificently varied of Nature's spectacles, the foundation—the canvas, so to speak—on which the picture is painted is pure white aerial vapor. The greatest depth of darkness in a daylight cloudscape is due to the massing overhead of enormous volumes of vapor, usually in electric conditions. When a storm has spent itself and the vast system drifts away from the zenith, we get a sight of the mountain ranges lately heaped above us, still black as night at the level base, but their flanks now dazzling white against the clearing blue. Under full sunlight the curved volutes of the cumulus, piled like buttresses against the lowering height of the central mass, show a notable feature on the darker edges outlining the immensely complex contours and enhancing the vivid impression of rocklike solidity given by the whole.

For example, when the cumuliform summits of heavy masses of cloud with great vertical development rise in the shape of mountains or towers, the upper parts, having a fibrous texture, spread out in the shape of an anvil. Then a strange medley of color effects may follow. When the cloud such as the cumulus or cumulonimbus is opposite the sun, the surfaces normal to the observer are brighter than the edges of the cloud's rounded protuberances. When the light comes from the side, the cloud may exhibit strong contrasts of light and shade. Against the sun, on the other hand, it may look dark with a bright edge or silver lining.

All clouds except the highest fields of cirrus have a light side and a shadowed one. There is also the range of hues visible at certain conjunctions in the clouds of sunrise or sunset, the passages of wild magnificence or inexpressible delicacy seen where the source of light near the horizon is tinged by the medium of earth-haze brought about by very mild condensation insufficient to create cloud.

In the broad illumination of noonday there are many variations of cloud color—always beautiful, always compelling, and apparently unaffected by any changes in the quality of the sun's light. When clouds are moving in open order and their drift is mainly at one level, they seldom occult each other's daylight; but when they lie at varying altitudes and are borne on cross currents, shadows may be cast from one to another, producing one of the most striking effects to be seen in our weather. When the sun is sufficiently high above the horizon during the day, cirrostratus is never thick enough to prevent shadows of objects on the surface of the earth. As it floats in the sky this cloud resembles a thin whitish veil which gives rise to halos, yet without in the slightest blurring the outlines of the sun or moon. Now it may be diffuse, giving the sky a milky appearance; again it may show more or less distinctly a fibrous structure with disordered filaments.

Though the white of clouds, flying fleeces or massive piles against the open blue of a forenoon sky, is as pure as the white of fresh-fallen drifts on a hillside or the wreaths which curl over on an Atlantic breaker, at certain hours it may take on the hue of a rose or a flame. Vapor has an infinite variety of colors proper to it, which, while they respond to the changes of light, seem to be inherent in its substance. Snow slopes and sea foam, though they can assume marvelous contrasts of blue shadow and fiery illumination, altogether lack the scale of grays and purples assumed by vapor. Lighted by high sun, the shadowed side of clouds is usually of a soft neutral gray; but in the more solid masses seen in heavy rain or thunderstorms, this gray deepens through many gradations to the deepest purple or blue-black. The opaque curtain of a coming downpour looks most menacing while the sunlight is full upon it; when the sun goes in behind the advancing veil, the cloud loses half its darkness and its threat.

Thunderstorms sometimes show tones not seen in any other natural condition—swarthy and metallic, olive-green and brownish—such as sometimes accompany a town fog. The enormous depth of cloud piled overhead in a great storm system is enough to produce an almost midnight blackness. Lightning is Nature's fiercest spectacle of beauty; thunder her vociferous reminder that her forces are mightier than the handiwork of man. A thundercloud seems all the more rugged from underneath, where it looks darker than a warm-front overcast because light is absorbed. Shafts of sunlight gleam in falling rain at the windtorn edges of the cloud.

But other hues beyond the scale of white through gray to black are to be seen in clouds of full daylight—tawny and ashy—not easily accounted for on the hypothesis of a pure base. The effect of shadow cast on cloud by cloud, as distinct from the shadow of the side turned away from the source of light, must be taken into consideration, as well as that of partial translucency, such as will turn the creamy smoke of a weed fire to tarnished bronze where it crosses the clear sky.

Another aspect of cloud color occurs when cold white cumulus stares against the dark hood of rising storm and its counterpart of black horizontal wisps stretched across the lower slopes of mountainous thundercloud, themselves lit with a somber glow. When the sun is low at dawn or sunset, its rays, striking aslant through layers of earth-haze near the ground, take color from them and throw it upon the clouds. As they traverse the landscape or scintillate lazily over sun-baked ground, low-lying cumulus of fine weather may gather into small-scale thunderheads and shed rain.

The splendors of dawn or close of day are always more vivid the nearer they are to the horizon—the threads of intense red fire, the islands of clear gold, the flush of crimson or rose on fields of cirrus, the orange and copper glow on banked cumulus or the fleecy cumulus of fine weather. The illumination at these moments is swiftly transient; the gray bars or dapple of the sky at dawn fire up and pass into the white of common daylight; the flames of sunset are quickly quenched, to leave only the dark drifts and wreaths of twilight.

While watching the display of aerial color, we are likely to forget the part played by the open heaven, the contrast between rosy mackerel skies or fiery streamers with the pale blues of the zenith or clear green of the lower spaces—backgrounds of living light against which the phantasmagoria of the tinted clouds is set.

The azure tint of the cloudless sky is due to the molecular scattering of light as it passes through air.

The blue and violet, being more refrangible than other colors of the solar spectrum, are more strongly scattered, and impart a blue color to the sky.

The thin and translucent edges of clouds often show irisations, phenomena corresponding in type to the corona. In fact, the presence of irisations is a sure sign of altocumulus as distinguished from cirrocumulus or stratocumulus. Similarly, a sheet of high altostratus is distinguished from a rather similar sheet of cirrostratus by the convention that halos are not seen in altostratus.

At sunrise and sunset, when the light traverses the greatest depth of atmosphere, all the colors are absorbed except the red and the yellow; and these, being reflected from the clouds, produce the brilliant coloring of dawn and sunset. Sunsets on southern seas display a gamut of magic colors without parallel in the North.

The eruption of Krakatoa in August 1883 distributed large quantities of dust through the atmosphere, leading to a series of most remarkable sunrises and sunsets in the British Isles and elsewhere during the months of November and December 1883 and January 1884.

Writing from Stonyhurst, England, December 21, 1883, the poet Hopkins gives the following word picture:

> The glow is intense, it has prolonged the daylight and optically changed the season; it bathes the whole sky. It is mistaken for the reflection of a great fire . . . more like inflamed flesh than the lucid red of ordinary sunsets. But it is also lusterless. A bright sunset lines the clouds so that their brims look like gold, brass, bronze or steel. It fetches out those dazzling flecks and spangles which people call fish scales. It gives to a mackerel or dappled cloud rack the appearance of quilted crimson silk or a plowed field glazed with crimson ice.

CHAPTER XI

CLOUD CODES AND WEATHER SYMBOLS

OBSERVING AND CODING OF CLOUD FORMS

When two or more layers of clouds are visible, the predominating cloud is that which is observed to cover the largest portion of sky at the time of observation. The U. S. Weather Bureau, in Circular S, W. B. No. 1249, "Codes for Cloud Forms and States of the Sky," and in Circular M, W. B. No. 1221, "Instructions to Marine Meteorological Observers" (pages 59-60), requests observers to enumerate all species or special forms of each cloud genus in determining the total amount of sky covered by that genus. The following Code Tables, as employed by the Weather Bureau when the information is transmitted by radio, refer to the forms of clouds and states of the sky, lower, middle, and upper levels:

1. FORM OF PREDOMINATING CLOUD (C)

Code figures	Form of Clouds	Code figures	Form of Clouds
1	Cirrus	6	Stratocumulus
2	Cirrostratus	7	Nimbostratus
3	Cirrocumulus	8	Cumulus or fractocumulus
4	Altocumulus	9	Cumulonimbus
5	Altostratus	0	Stratus or fractostratus

2. FORM OF LOWER CLOUDS (C_L)

Code figures	Form of Clouds
0	No lower clouds
1	Cumulus of fine weather
2	Cumulus heavy and swelling, without anvil top
3	Cumulonimbus
4	Stratocumulus formed by the flattening of cumulus clouds
5	Layer of stratus or stratocumulus
6	Low broken-up clouds of bad weather

7	Cumulus of fine weather and stratocumulus
8	Heavy or swelling cumulus (or cumulonimbus) and stratocumulus
9	Heavy or swelling cumulus (or cumulonimbus) and low ragged clouds of bad weather

3. FORM OF MIDDLE CLOUDS (C_M)

Code figures	Form of Clouds
0	No middle clouds
1	Typical Altostratus, thin
2	Typical altostratus, thick (or nimbostratus)
3	Altocumulus, or high stratocumulus, sheet at one level only
4	Altocumulus in small isolated patches; individual clouds often show signs of evaporation and are more or less lenticular in shape
5	Altocumulus arranged in more or less parallel bands, or an ordered layer advancing over sky
6	Altocumulus formed by a spreading out of the tops of cumulus
7	Altocumulus associated with altostratus, or altostratus with a partially altocumulus character
8	Altocumulus castellatus, or scattered cumuliform tufts
9	Altocumulus in several sheets at different levels, generally associated with thick fibrous veils of cloud and a chaotic appearance of the sky

4. FORM OF UPPER CLOUDS (C_H)

Code figures	Form of Clouds
0	No upper clouds (no high clouds)
1	Cirrus, delicate, not increasing, scattered and isolated masses
2	Cirrus, delicate, not increasing, abundant but not forming a continuous layer
3	Cirrus of anvil clouds, usually dense
4	Cirrus, increasing, generally in the form of hooks ending in a point or in a small tuft

5	Cirrus (often in polar bands) or cirrostratus advancing over the sky but not more than 45° above the horizon
6	Cirrus (often in polar bands) or cirrostratus advancing over the sky and more than 45° above the horizon
7	Veil of cirrostratus covering the whole sky
8	Cirrostratus not increasing and not covering the whole sky
9	Cirrocumulus predominating, associated with a small quantity of cirrus

5. TOTAL AMOUNT OF ALL CLOUDS (N), REGARDLESS OF KIND

Code figures	Proportion of Sky Covered (in Tenths)
0	0
1	Less than 0.1
2	0.1
3	0.2 to 0.3
4	0.4 to 0.6
5	0.7 to 0.8
6	0.9
7	More than 0.9 but with openings
8	Sky completely covered with clouds
9	Sky obscured by fog, dust storm, or other phenomenon

Code figure 0 is to be used only when the sky is completely free from clouds.

Code figure 8 is to be used only when the sky is completely covered with clouds, so that no blue sky is visible.

Code figure 9 should be reported only if the sky is invisible, owing to fog.

6. AMOUNT OF LOWER CLOUDS (N_h): The Total Amount of Lower Clouds is Coded According to the Scale and Table Used in Reporting the Total Amount of All Clouds (N).*

* *Instructions to Meteorological Observers,* Circular M, W. D. No. 1221. By permission of the U. S. Weather Bureau.

7. HEIGHT OF BASE OF CLOUD (h)

Code figures	Height in Feet	Code figures	Height in Feet
0	Zero to 150	5	2,000 to 3,000
1	150 to 300	6	3,000 to 5,000
2	300 to 600	7	5,000 to 6,500
3	600 to 1,000	8	6,500 to 8,000
4	1,000 to 2,000	9	No low cloud below 8,000

KEY TO IDENTIFICATION OF CLOUD CODE TYPES *

The first step is to determine whether the clouds are at lower, middle, or upper levels. If clouds at more than one level are present, the observer should determine which clouds belong to each of the three principal levels. . . .

Certain combinations are rare or difficult to identify.

UPPER CLOUDS [1]

Detached or in groups or patches					Layer or sheet covering ail or a part of the sky				
Increasing		Stable or decreasing			Increasing			Stable	
		Delicate		Dense	Below 45°	Above 45°			
Delicate, usually with hooks or tufts	More or less dense, probably derived from anvil	Scarce	Abundant	Probably derived from anvil	Sheet of cirrostratus or of fibrous cirrus merging into cirro-stratus	Not covering whole sky	Has recently extended over whole sky	Covering whole sky	Covering almost but not quite whole sky
H_4	H_3	H_1	H_2	H_3	H_5	H_6	H_7	H_7	H_8

[1] If cirrocumulus predominates, use code H_9

* *Codes for Cloud Forms and States of the Sky,* Circular S, W. B. No. 1249. Quoted by permission of the Weather Bureau.

MIDDLE CLOUDS *

In groups, patches or layer with openings					Continuous layer or sheet		
Spreading or advancing over the sky		With cumuliform tufts	Stable or evaporating		Lowering or thickening		Degenerating
					Thin	Thick	Thick
Derived from cumulus	In parallel bands or ordered layer	(Castellatus)	Lenticular	In single layer	(Typical thin altostratus)	No definite relief under surface	Altocumulus or altocumulus associated with altostratus, with definite relief on under surface
M_6	M_5	M_8	M_4	M_3	M_1	M_2	M_7

* Altocumulus in the typical chaotic, thundery type of sky is coded M_9.

LOWER CLOUDS

Detached masses						Sheet or layer				
With vertical development			Without vertical development							
				Low bad weather clouds						
Small, with slight vertical development (typical fair weather type)	Active vertical growth without fibrous summit	Great vertical growth with fibrous summit	Spread out from cumulus	Under altostratus or nimbostratus	Under cumulonimbus	Single layer of stratus or stratocumulus	Low clouds of bad weather fused into continuous sheet	Stratocumulus with fair weather cumulus below	Stratocumulus with towering cumulus below or with cumulus or cumulonimbus penetrating the layer	Cumulonimbus covering the sky with ragged low clouds of bad weather below
L_1	L_2	L_3	L_4	L_6	L_9	L_5	L_6	L_7	L_8	L_9

SKY AND CLOUDS IN A TYPICAL DISTURBANCE

Since the temperature, moisture, and movements of the air differ characteristically at the various levels above the surface of the earth, there are significant differences in the form of clouds as well as in the apparent effects of distance or height above the observer. The following diagram and notes from the International Atlas show the distribution of cloud and sky types in the various sectors of a physical disturbance.

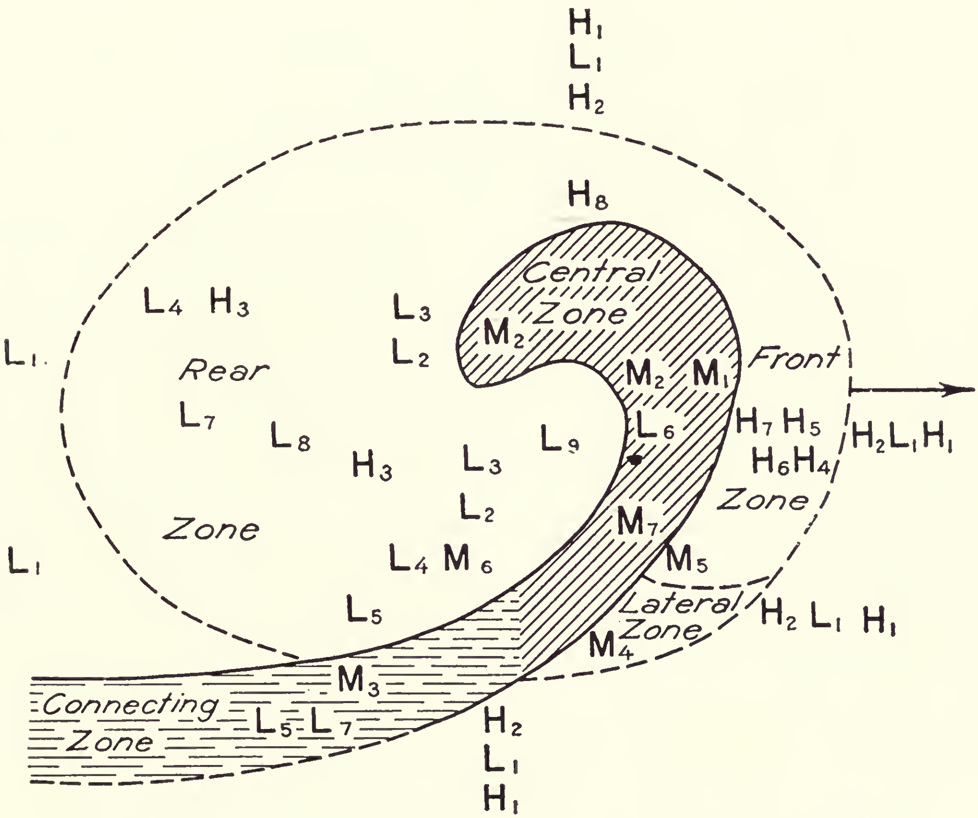


Figure 5.—Diagram of a Typical Disturbance. (From the "International Atlas.")

1. This diagram corresponds with a typical disturbance—to be precise, the first of a family—arriving from the west in western Europe.

2. It sometimes happens that the rear zone is much more extensive and that it persists for several days over the same region.

3. Fractocumulus may occur practically anywhere in the rear zone.

4. The specifications M_8 and M_9 correspond respectively with the

Symbol	Meaning	Remarks
◍	Rain.	
✳	Snow.	
✹	Rain and snow together ("sleet" of British usage).	
	Thunderstorms.	Thunder and lightning.
T	Thunder.	Without lightning.
≤	Lightning.	Without thunder; "heat-lightning."
▲	Hail.*	
△	Graupel.	Sometimes called "soft hail." French, *gresil.* Resembles little snow-pellets.
≡	Fog.	
≡	Ground fog.	Not exceeding the height of a man.
≡:	Wet fog.	One which wets exposed surfaces.
⊔	Hoarfrost.	
	Dew.	
V	Rime.	A rough frost deposit from fog.
∽	Glaze; glazed frost.†	Ice coating due to rain, "ice-storm." In America, often called "sleet."
	Driving snow.	Ger., *Schneegestober;* Fr., *bourrasque de neige.*
←	Ice-crystals.	Ice-needles, sometimes seen floating or slowly falling in the air in clear, cold weather.
⊠	Snow on ground.	Ground near station more than half covered.
	Gale.	Wind of force 8-12, Beaufort scale. (Rept. Int. Met'l Comm., Berlin, 1910, English ed., p. 17.) Formerly used for "strong wind." A 3-barbed arrow is introduced in the 2d German ed. of the Int. Met'l Codex to denote "strong wind," but no authority is cited. According to the Observer's Handbook of the British Met'l Office, "the number of barbs on the arrow may conveniently be made to represent the strongest wind force noted," but there is no international sanction for such variants.
⊙	Sunshine.	In German edition of Int. Met'l Codex, but has never been definitely recognized by the international organization. (See Rept. Int. Met'l Comm., Southport, 1903, Engl. ed., pp. 19 and 101.) Widely used in German and Austrian publications.
⊕	Solar halo.	
	Solar corona.	
	Lunar halo.	
	Lunar corona.	
⌒	Rainbow.	
	Aurora.	
	Zodiacal light.	
∞	Haze.	Due to fine dust, or to the disturbance of atmospheric transparency by air-currents of different densities ("optical turbidity"), and not to water-drops. In practice, this is often difficult to distinguish from light fog (≡°), or "mist" of British observers. Prussian and Austrian observers underscore this symbol (∞) to denote a definitely *smoky* atmosphere ("Moorrauch").
	Mirage.	
0	Exceptional visibility.	
≡S≡	Sand storm or dust storm.	

* True hail, which occurs chiefly with summer thunderstorms, should be distinguished from the snowy pellets, like miniature snowballs, known as graupel, or soft hail (△); also from the small particles of clear ice, called sleet by the U. S. Weather Bureau, for which there is no international symbol. On the history of the word sleet, see Monthly Weather Review, May, 1916, pp. 281-286.

† Glaze is the official term in the United States; glazed frost in Great Britain.

Figure 6.—International Meteorological Symbols

front or lateral sector and with the central or rear sector of a thunderstorm disturbance. They can find no place in this diagram, which is that of a normal disturbance.

5. Observers should not take the form of cloud corresponding with the position in this diagram as necessarily determining the form of cloud to be reported.

STATES OF THE WEATHER

The International classification gives a hundred states of the "weather," that is, phenomena occurring in connection with precipitation, present or imminent, or atmospheric disturbances of more or less localized extent and effect. They are symbolized for use on weather maps internationally as shown in Figure 6.

On the pages immediately following is reproduced United States Weather Bureau Chart, "Explanation of Weather Code Numbers and Symbols" * (Figure 7) and "Symbolic Form of Weather Code" (Figure 8).

SYNOPTIC WEATHER CHART

A synoptic weather chart is a map on which are represented the prevailing meteorological conditions at a given moment of time over the area covered by the map, generally on the basis of simultaneous weather observations made at a network of stations. To conserve space, weather codes and symbols are used to enter complete data on the maps.

An isogram is a line drawn to show the distribution of a physical condition in space or time or both by connecting points corresponding to equal values of the phenomenon represented. Most of the isograms used in meteorology are on geographical charts and show the distribution of a physical condition in space only. Special forms of isograms are as follows:

Isallobars, usually drawn as short dashed curves, are lines of equal pressure tendency, and show the rise of barometric pressure within a specified period.

Isotherms, drawn lightly in blue for 10-degree intervals, are lines of equal temperature.

Isobars, often labeled in both inches of mercury and millibars, show

* By permission of the United States Weather Bureau.

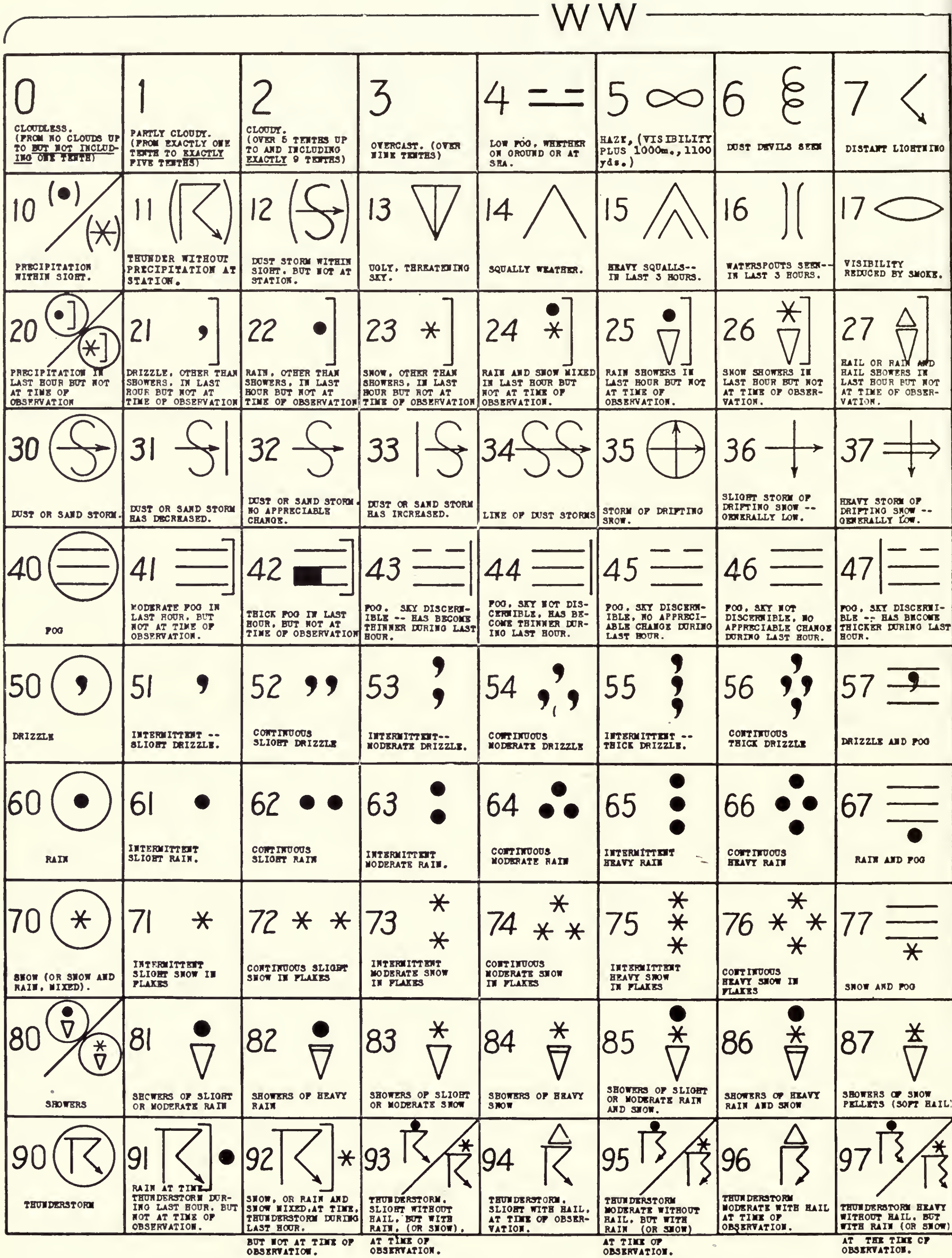


Figure 7.—Explanation of Weather Code Numbers and Symbols

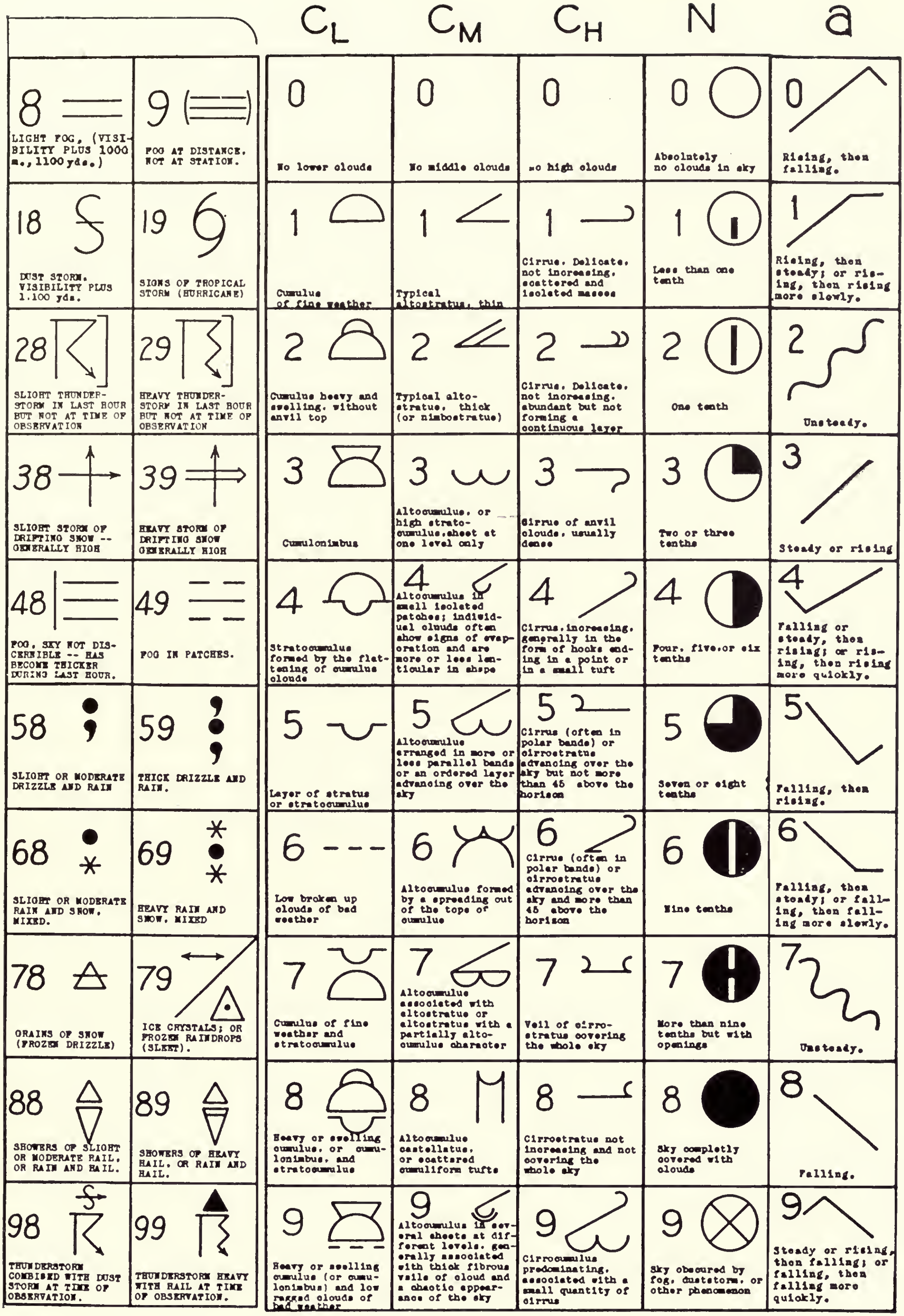
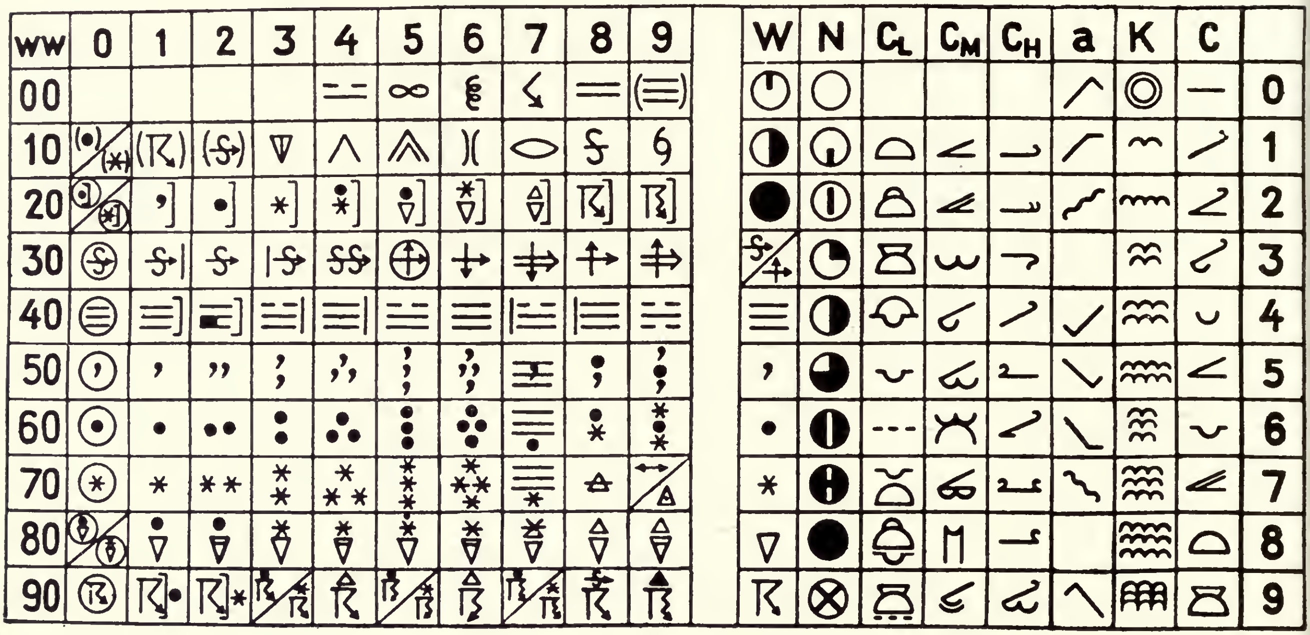


Figure 7.—Explanation of Weather Code Numbers and Symbols

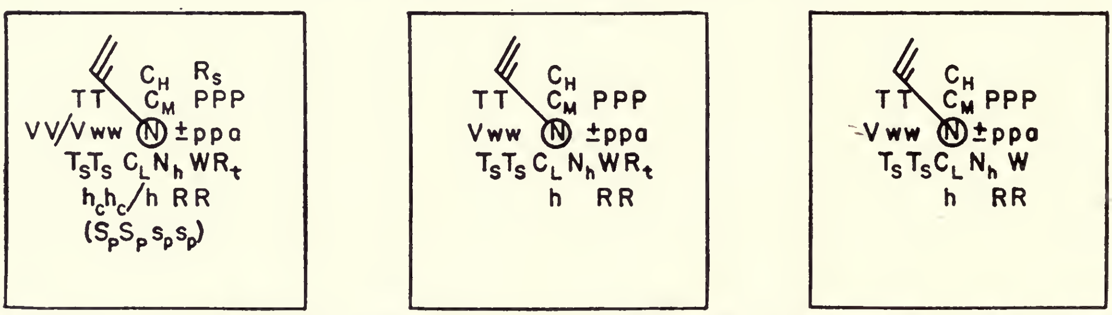
SYMBOLIC FORM OF WEATHER CODE

SYMBOLS:	$IIIC_LC_M$	$wwVhN_h$	DDFWN	PPPTT	UC_Happ
MESSAGE:	0006 2	7 2 5 2 6	2 8 5 6 8	9 5 3 3 1	9 0 4 1 4
SYMBOLS:	$T_ST_SD_CT_{n/x}T_{n/x}$	$7h_ch_cVV$	$8R_sR_tRR$	$9P_mP_mP_ma_3$	$0S_pS_ps_ps_p$
MESSAGE:	30731	7 0 6 1 3	8 2 4 4 5		0 2 8 4 1

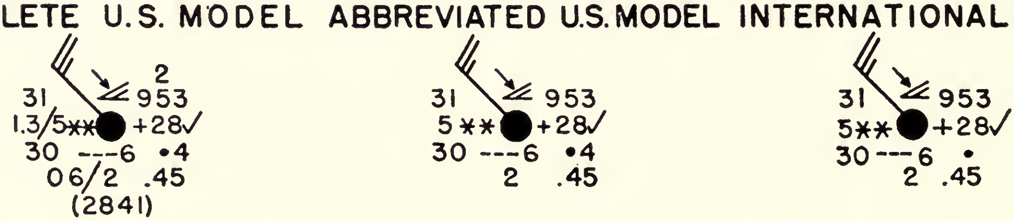
TABLE OF SYMBOLS



STATION MODELS



COMPLETE U.S. MODEL ABBREVIATED U.S. MODEL INTERNATIONAL MODEL



NOTE: In the complete U.S. Model and the Abbreviated U.S. Model all entries are made in black. In the International Model C_H, W, V, and T_sT_s (also pp when negative) are usually entered in red.

Figure 8.—Symbolic Form of Weather Code

the horizontal distribution of atmospheric pressure reduced to sea level, or the pressure at some specified altitude.

Isopleths show the variation of a meteorological element in relation to time of the year (month) and the other usually the time of day (hour), but sometimes space (especially altitude).

Anisallobars show rise of barometric pressure in a given time.

Isanomals, or isanomalous lines, show the departure of the local mean value of an element from the mean pertaining to the latitude.

Katisallobars are the isograms of the fall of barometric pressure in a given time.

The pointed-sawtooth line on Figure 10 shows the boundary or "front" of advancing air. Hatched areas indicate areas of continuing precipitation. Arrows fly with the wind, and the number and length of barbs show the wind strength; the number to the left of each station is the Fahrenheit temperature; the number to the right is the net change in the barometer (in millibars and tenths of millibars) during the preceding three hours, and the accompanying symbol shows the character of the barograph trace during that interval. Note the comparative uniformity in temperature over large areas ahead of the front, and the abrupt decrease at and behind the front. Note also the abrupt change in the barometric tendencies at the front.

The daily weather map on page 259 (Figure 10) is accompanied by the following explanation, prepared by the United States Weather Bureau:

At 2:30 a.m., E. W. T., observations of the weather are taken at several hundred stations throughout the United States. Reports from 170 of these stations are inscribed on the above map. Temperature, wind direction, and velocity, amount and kind of clouds, state of weather, visibility, amount of precipitation, and other meteorological data are indicated for each station.

The heavy lines are called "fronts" and separate the air masses of different characteristics. The labels which are made up of letter combinations indicate particular types of air masses. Fronts and labels are described [below].

The light, continuous lines are called isobars and pass through points of equal sea-level pressure. The dashed line (when present) is an isotherm and passes through all points where the current temperature is 32° Fahrenheit. This line is labeled "Freezing" and separates the respective areas which are above and below the freezing temperature of 32° Fahrenheit.

The figures and symbols for the data always occupy approximately the same positions around the station circle, as shown on the [Figure 9], "Station Model."

The geographical area where precipitation is falling at 2:30 a.m., E. W. T., is covered with dot shading. The letter "T" is used to indicate a "Trace" of precipitation, which is an amount too small to measure.

The table values in feet for the figures used for the "height of lower clouds" are as follows: 0 = 0 to 163 feet; 1 = 64 to 327 feet; 2 = 328 to 655; 3 = 656 to 983; 4 = 984 to 1967; 5 = 1968 to 3280; 6 = 3281 to 4920; 7 = 4921 to 6561; 8 = 6562 to 8201; and 9 = above 8202 feet or no clouds.

The table range values in miles for the figures used for "visibility" are as follows: 0 = less than 1-thirty-second mile (55 yards); 1 = from 1-thirty-second up to, but not including, 1-eighth mile (220 yards); 2 = from 1-eighth up to, but not including, 5-sixteenths mile (550 yards); 3 = from 5-sixteenths up to 5-eighths mile (1100 yards); 4 = up to 1 and 1-fourth miles; 5 = up to 2 and 1-half miles; 6 = up to 6 miles; 7 = up to 12 miles; 8 = up to 30 miles; 9 = 30 miles or more.

The symbol within the station circle indicates the total amount of all clouds. A figure is also entered for the "amount of clouds whose height is given by h." The values for N and N_h are as follows: 0 ○, absolutely no clouds; 1 ⦶, sky less than 1-tenth covered; 2 ⦶, 1-tenth covered; 3 ◔, 2- or 3-tenths; 4 ◑, 4-, 5-, or 6-tenths; 5 ◕, 7- or 8-tenths; 6 ●, 9-tenths; 7 ●, more than 9-tenths, but with openings; 8 ●, 10-tenths, or completely covered; 9 ⊗, sky obscured.

The symbol directly to the left of the station circle represents the current state of weather and may be any one of 96 separate symbols. The basic symbols for preciptation are: , drizzle; • rain; ✱ snow; ∇ showers; ⌈⚡ thunderstorm. A symbol for current state of weather is always used when precipitation is falling or when unusual conditions are observed. Some of the frequently used symbols are as follows: ∞ haze; ⚡ distant lightning; = light fog; ⊂⊃ smoke; ✱] snow in last hour, but not at time of observation; § dust storm; ≡ fog; sky not discernible; ,,, continuous moderate drizzle; • intermittent light rain; ✱✱ continuous light snow; •∇ light or moderate rain showers; •⌈⚡ thunderstorm with rain. Symbols are entered singly or in combination, for example, a • represents rain and three bars ≡ represents fog. Three bars and a dot ≡• represent rain and fog. The bracket sign] means "in past hour, but not at time of observation."

The shaft of the arrow extends from the station circle in the direction *from which* the wind blows and the feathers on the shaft show the force of the wind on the Beaufort Scale. Each feather represents *two* units of force and each *half feather* represents *one* unit of force. For example, a wind blowing *from the east* at 5 miles an hour would be drawn  and would be described as an "east wind, force 2";  is a "west-southwest wind, force 5."

FRONTS AND LABELS

The boundary between two different air masses is called a "front." Important changes in weather often occur with the passage of a front. The half circle and triangular points placed on the "front" lines are symbols to indicate the classification of the front and its direction of movement. The boundary of relatively cold air of polar origin advancing into an area occupied by warmer air of tropical origin is called a "cold front." The boundary of relatively warm air advancing into an area occupied by colder air of polar origin is called a "warm front." The line along which a cold front overtakes a warm front is called an "occluded front." A boundary between two air masses which shows little tendency at the time of observation to advance into either the warm or the cold air areas is called a "stationary" front. The front symbols, with arrows to show their direction of movement, are given below:

 Warm front at the ground. Warm front above the ground.
 Cold front at the ground.  Cold front above the ground.
 Occluded front.  Stationary front.

The words "HIGH" and "LOW" indicate high and low barometric pressure.

Masses of air are classified into several different types which indicate their origin and basic characteristics. For example, the letter "P" denotes the polar type of relatively dry and cold air from northerly or polar regions. The letter "T" denotes the tropical type of relatively moist and warm air from southerly and tropical regions. The letters placed *before* the letters "T" and "P" show that the air mass is classified as Maritime (M) or Continental (C). The letters placed *after* "T" and "P" show that the air mass is colder (K) or warmer (w) than the surface over which the air is moving. Mixtures of air masses are denoted by plus signs (+), and transitional changes of air masses from one type to another are indicated by arrows (⇒). One air mass superimposed upon another is indicated by placing a line between the two labels.

P = Polar; C = Continental; T = Tropical; M = Maritime; S = Superior (very dry); A = Arctic; K = Colder; w = Warmer.

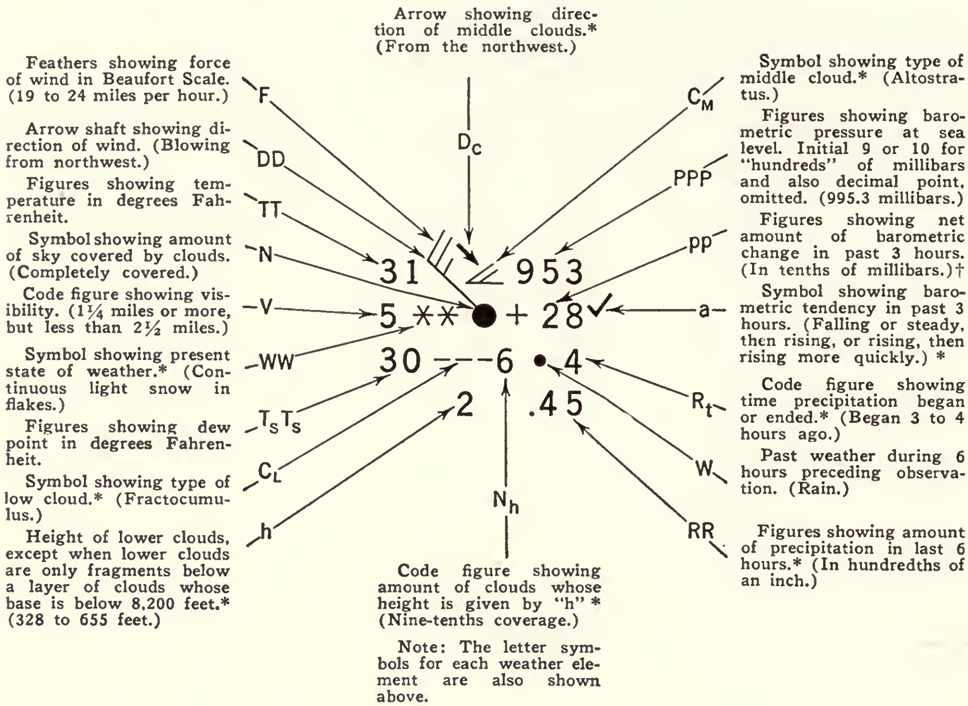
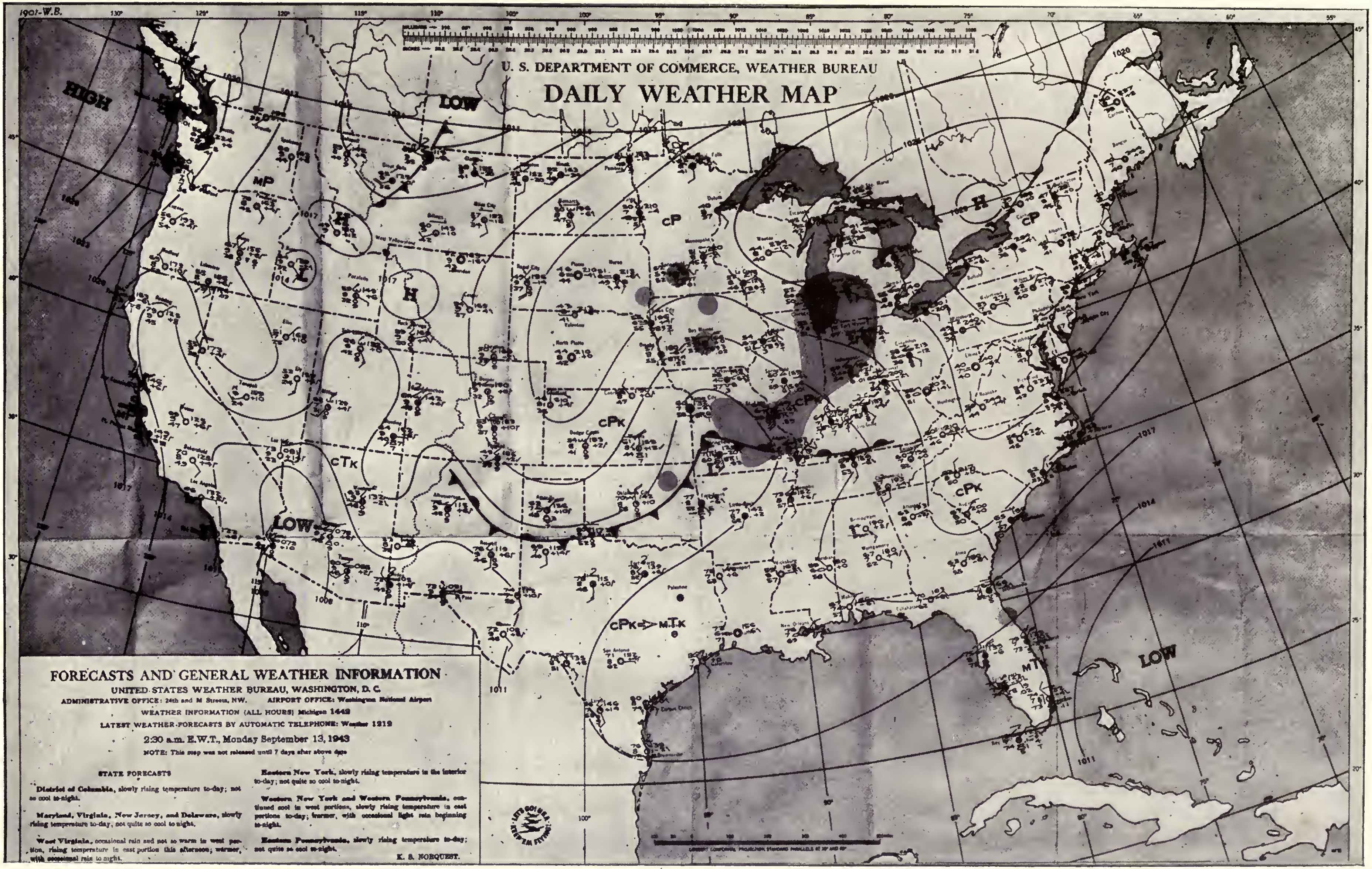


Figure 9.—Station Model.

Weather maps are drawn to follow the movements of air masses and thus enable weather forecasters to determine the probable direction of winds and the general aspects of the weather. Lows, as shown on the maps, indicate low-pressure areas or storm centers. The direction of the wind in these centers is generally counterclockwise. Thunderstorms, low-lying clouds, rain, and strong winds are characteristic of low-pressure conditions.

* Omitted when data are not observed or are not recorded.

† A plus or minus sign is used to show whether pressure is higher or lower than 3 hours ago.



1901-W.B.
U. S. DEPARTMENT OF COMMERCE, WEATHER BUREAU
DAILY WEATHER MAP
HIGH
LOW
LOW
LOW
H
H
H
mP
cP
cP
cPk
cPk
cPk
cTk
cPk ⇒ mTk
mT
FORECASTS AND GENERAL WEATHER INFORMATION
UNITED STATES WEATHER BUREAU, WASHINGTON, D. C.
ADMINISTRATIVE OFFICE: 24th and M Streets, NW.
AIRPORT OFFICE: Washington National Airport
WEATHER INFORMATION (ALL HOURS) Michigan 1442
LATEST WEATHER FORECASTS BY AUTOMATIC TELEPHONE: Weather 1212
2:30 a.m. E.W.T., Monday September 13, 1943
NOTE: This map was not released until 7 days after above date
STATE FORECASTS
District of Columbia, slowly rising temperature to-day; not so cool to-night.
Maryland, Virginia, New Jersey, and Delaware, slowly rising temperature to-day, not quite so cool to night.
West Virginia, occasional rain and not so warm in west portion, rising temperature in east portion this afternoon; warmer, with occasional rain to night.
Eastern New York, slowly rising temperature in the interior to-day; not quite so cool to-night.
Western New York and Western Pennsylvania, continued cool in west portions, slowly rising temperature in east portions to-day; warmer, with occasional light rain beginning to-night.
Eastern Pennsylvania, slowly rising temperature to-day; not quite so cool to-night.
K. S. NORQUEST.

CHAPTER XII

WORLD ASPECTS

WORLD CLOUDINESS

The sea is generally cloudier than the land; summer is cloudier than winter; and, except in July, the Southern Hemisphere is cloudier than the Northern. The mean cloudiness over the whole earth is calculated as 5.44 tenths of the sky; the annual variation is very small, ranging only from 5.34 tenths in March and April to 5.53 tenths in July.* Cloudy days and cloudy summers are relatively cool; while cloudy nights and cloudy winters are relatively warm.

To some extent these variations are due to the circumstance that continents as a whole are warmer in summer and cooler in winter than adjacent oceans, the reason being that water requires more heat than land to raise the temperature, reflects a much greater proportion of heat, transmits heat absorbed to a much greater depth, and expends a large proportion of it in evaporation. The sun, as we know, is the principal source of all heat. Negligible sources are the earth's interior and other planets, which account for less than 0.25° F. As a consequence, land is warmer in summer; but, since it does not retain heat as readily as water, it is cooler in winter. The same difference, in a smaller degree, obtains between day and night in coastal regions, and results in land breezes at night and sea breezes during the day. At the earth's surface the mean annual temperature near the Equator is 50° C. warmer than near the poles; but at 65,000 feet (20 kilometers) above the surface, the temperature over the poles is 50° C. warmer than over the Equator.

IF THERE WERE NO CLOUDS

The average temperature over the entire surface of the earth is

* C. E. P. Brooks, D. Sc., "On the Mean Cloudiness over the Earth." In *Memoirs of the Royal Meteorological Society,* I (Nos. 1-10, 1926-7), 156. "From observations at more than 1,000 well distributed land stations and data for marine 'squares' in the Atlantic and Indian oceans, the mean cloudiness was calculated for each 10-degree belt of latitude, for each month and the year, for land and sea separately and together. The cloudiest belts over the land were found to be 60° to 70° North and 50° to 60° South; over the sea, 60° to 70° North and South. The clearest belts over the land were 20° to 30° North and South; over the sea, 20° to 30° North and 10° to 20° South."

59° F., or 7 degrees higher than it is estimated that it would be if the air were perfectly transparent to both solar and terrestrial radiation, and if there were no clouds. This difference is due almost entirely to the water vapor in the air, which varies in different parts of the earth, also in the same place from time to time. Dry air transmits the earth's radiant heat and gives low night temperature. Moist air absorbs and returns the earth's radiation, often resulting in a warm, muggy night temperature. Since the moist air will not allow the earth's heat to escape, in moist equatorial regions the nights are warm. On the other hand, in the arid desert, the nights are cold because there is insufficient water vapor in the air to absorb and return to the surface enough of the earth's radiation to maintain the temperature. Thus, the extraordinary winter cold of Siberia is due in large measure to the extreme dryness of the air.

VARIATIONS IN CLOUDINESS

At what times during the day and year do the skies in temperate latitudes shown maximum and minimum degrees of cloudiness?

DIURNAL VARIATION: During the day there is a maximum cloudiness about noon, and a minimum in the late evening. Owing to the frequency of clouds of the cumulus type during the summer, the variation is pronounced so far as the nights are concerned and less so in the daytime.

ANNUAL VARIATION: On the basis of annual variation in the temperate latitudes, maximum cloudiness occurs in the winter and minimum in the summer and early autumn.

Variations, both diurnal and annual, in the maximum and minimum degrees of cloudiness are different over varied land areas and over the oceans, especially late at night. They vary also in different parts of the world, particularly in the tropics. The above applies only to our ordinary temperate climate.

As a rule clouds are lower in winter than in summer, and for the same reason lower in the polar regions than in the tropics. In fact, some of the highlands of Asia are above the snow clouds. The difference in height is due to difference in humidity. The greater the humidity, the less height to which a body of air must ascend to become cold enough to form a cloud. The winter humidity is high because the cold, wet ground is constantly giving off moisture to the cool air above, which because of its coolness becomes more quickly saturated.

COMPARATIVE SEASONAL AND ANNUAL TEMPERATURES *

(Northern and Southern Hemispheres and of the Earth as a whole, as Indicated by Averages for January, July and the year, in Centrigrade Degrees)

	Year	Summer	Winter	Difference
Northern Hemisphere	15.2	22.4	8.1	14.3
Southern Hemisphere	13.3	17.0	9.7	7.3
Difference	1.9	5.4	—1.6	...
Earth	14.3	16.0	12.6	3.4

The table above shows average temperatures for each hemisphere as a whole and of the entire earth, so far as they can be ascertained from available meteorological data. Note that the contrast between seasonal temperatures is greater in the Northern Hemisphere than in the Southern; that the average temperature of the Southern Hemisphere during the summer is lower than that of the Northern Hemisphere during its summer, while the southern winter is warmer than the northern one.

"It is easily shown that the total amount of solar radiant energy intercepted annually is the same in the two hemispheres. However, on the average for the year, the southern hemisphere as a whole is cooler than the northern, even though its average elevation above sea level is 100 meters less. Moreover, the annual average temperatures of the torrid zone and of the temperate zone separately are each lower in the southern hemisphere than in the northern; and up to latitude 75°, the southern hemisphere averages cooler in all four seasons than the northern hemisphere up to the corresponding latitude."

EFFECT OF UNEQUAL DAYS AND NIGHTS ON TEMPERATURE

In each hemisphere the heating power of the sun is greatest at the period of the longest day because of its greater altitude in the heavens, and least at the period of shortest days. Thus inequality in the length of the days in different parts of the year, occasioned by the inclination of the earth's axis to the plane of its orbit, is of itself sufficient to produce a marked variation in temperature, hence in cloud formation.

* Edgar W. Woolard, "The Modification of Solar Climates by Meteorological Influences." In *Popular Astronomy,* XLVIII, No. 6 (June 1940), 9.

The following table gives the length of the longest day, excluding the time of twilight, and of the shortest night, in the different latitudes, with the difference of duration in hours and minutes.

TABLE OF UNEQUAL DAYS AND NIGHTS

Latitude	Longest Day (Hours)	Shortest Night (Hours)	Difference (Hours)
Equator	12.0	12.0	00.0
10	12.7	11.3	1.4
20	13.3	10.7	2.6
Tropics	13.5	10.5	3.0
30	14.0	10.0	4.0
35	14.5	9.5	5.0
40	15.0	9.0	6.0
45	15.6	8.4	7.2
50	16.3	7.7	8.6
55	17.3	6.7	10.6
60	18.7	5.3	13.4
Polar Circles	24.0	0.0	24.0
67½	1 month	0.0	
69½	2 months		
73.3	3 months		
78.3	4 months		
84	5 months		
North Pole	6 months		

During the day the earth receives from the sun more heat than it radiates into space; while during the night it radiates more than it receives. Hence a succession of long days and short nights results in an accumulation of heat, raising the average temperature and producing summer; while long nights and short days result in a temperature below the average, producing winter.

WORLD CLIMATE

World climate shows a trend toward warmer weather, with winters growing milder. Weather records show that in the past two decades the cities of Portland and Washington, 17 of the 20 years have been warmer than normal.

Alaska shares in the warmer trend, as is apparent from the advance of the forest line into the treeless tundra at the rate of one mile a century. Discovery of coal and fossils by a geological party of the Byrd Expedition in 1934 points to the possibility that the south polar region may once have enjoyed a mild and humid climate.

CHAPTER XIII

PAGEANT OF THE SKY—A SUMMARY

Nothing that is can pause or stay;
The moon will wax, the moon will wane,
The mist and cloud will turn to rain,
The rain to mist and cloud again.

—Longfellow.

A link connecting many phenomena between the earth and the sun, weather commences with the release of energy within the sun. The earth can intercept only about one two-billionth part of the sun's total output of energy, which comes to our planet as radiant energy of all wave lengths. The normal infrared and visible radiation from the sun warms the atmosphere, the land, and the oceans. Indeed, our atmosphere provides a sort of buffer state. The topmost layers receive a severe bombardment of high-frequency waves direct from the sun; the lower layers constitute a screen which enables the earth to retain during the night a considerable portion of the heat generated by the sunshine that has pierced its area. Were it not for this screening the earth would be subjected to very marked extremes of temperature as between day and night. On the same principle, the lower and more dense the clouds, the less the fall of temperature at night.

Not only does the sun evaporate the water in the oceans; it is also responsible for the rising of warm air containing this moisture to where it forms clouds, composed as they are of tiny water droplets each with a nucleus of dust at its core. In smoky industrial areas where the condensation nuclei are greasy and sooty, fogs are constituted in this manner.

Even the purest air contains fine particles in suspension, a great deal of it sometimes volcanic dust, the product of some eruption perhaps three or four thousand miles away.

The inevitable ascent of the warm air to the greater heights causes it to expand and cool; and, if it contains enough moisture, results, as we have observed, in the formation of clouds. The sequence of clouds accompanying a low-pressure area is the most important series of weather signs in the sky. Some clouds are fair-weather clouds, associated with high-pressure areas. By persistent watching of this cycle, combined with a knowledge of upper-air conditions and of the progress of the storm in adjacent regions, one can learn what kind of weather to expect.

Some thousands of feet above the surface of the earth, the winds blow the tops off approaching storm clouds. At these heights the temperatures are so low that clouds are formed of ice crystals—small traces of moisture turned into ice. These high-velocity winds, being stronger than the winds at lower levels, blow ahead of the coming storm the feathery wisps of cirrus or cirrostratus clouds which cause halos.

Ice crystal clouds of the higher brackets in cloud classification may be almost invisible to an observer on the earth's surface, yet the light of the sun or moon feebly shining through is refracted in such a manner that a halo—a good weather sign—is formed.

The commonest halo is a ring of 22° radius around the sun or moon. Most halos are prismatically colored, which explains why they are so often confused with rainbows. When they are bright enough, they show these distinct colors: red at the inner edge, yellow next, and a trace of blue or violet at the outer edge. In most lunar halos, however, the light is so faint that the colors are hardly perceptible. In all cases they are due to the presence of ice crystals in the air. Although in our latitudes the halo-forming crystals are mostly confined to high clouds of the cirrostratus variety, in the polar regions ice particles suspended in the lower air often form halos close to the observer.

The formation of a rainbow depends upon the passage of light through water droplets. The common primary and secondary bows directly opposite the sun or moon as the case may be, are seen in falling raindrops and also in the spray of waves, water falls, and lawn-sprinklers. The rainbow is rarely seen in winter because there is so seldom a combination of sun and rain at that season. It is not seen at noon—except in higher latitudes—because the sun must be less than 42° above the horizon.

Both halos and rainbows are to be distinguished from the corona—the diffuse reddish or rainbow-tinted ring around the sun or moon, seen through fleecy clouds due to the diffraction of light by water drops.

Eventually, while the sky turns a gray color indicative of a low-pressure area and an approaching rain storm, the clouds thicken and become larger in size. Known as altostratus, they lack the feathery or lacy fibrous contours of cirrus. Subsequent developments will depend upon the intensity of the coming storm. As the altostratus clouds become more dense and proportionately thicker, one may expect the lower spreading stratus to follow, with nimbostratus directly behind and heavy rain in their wake.

The sequence may include cumulonimbus, the grotesque thunderhead prevalent during the spring and summer, especially on humid or oppressively warm days. Growing in size from ordinary cumulus, they take in additional squall clouds to form what meets the eye as an extensive low, rolling front.

As the cloud creation approaches it assumes a massive anvil or turret-shaped top, and in itself becomes a regular "factory of clouds." The sky darkens, and huge raindrops may may fall in advance of driving sheets of rain. As rapidly almost as it appeared, the rain cloud will disappear; and, coupled with a rising barometer, should the wind change from points south or southwest to northwest, there will be little or no rain before the sky clears. On the other hand, should the barometer fall rapidly and the wind back from its former setting to southeast or south, rain may be expected within at least 36 hours.

Water vapor, mist, and cloud thus play a conspicuous part in the pageant of the sky—the drama of the weather. Water vapor coming in contact with a surface sufficiently cooler than itself condenses, and the dust in the air pervades such surfaces, and so enables the water vapor to condense into water.

Plowed fields absorb heat faster than do grass and rough water surfaces. Consequently, updrafts and thermal currents are more likely to be found over the former than over the latter. On an overcast day with clouds obscuring the sun, heat transference from earth to air is retarded and flying is smoother. On a clear day the earth receives more direct heat from the sun than on an overcast day.

A substantial portion of this heat is transferred by conduction and radiation to the layer of air immediately above the earth. Due to unequal heat reflection and absorption of different kinds of earth surfaces, some of this air, rising faster at points, causes thermal currents. Atmospheric currents in a massive convectional system result from the heating of the earth in equatorial regions. Chilly air flows in from higher latitudes as air heated near the earth's surface in the tropics rises to higher levels.

A layer of ozone exists at an average height of 14 miles, but probably occupying a region reaching from 9 to 22 miles. The relatively small amount of ozone in this layer protects us against the very dangerous radiations in the ultraviolet zone of the sun's light. Inasmuch as an increase of heat from the sun results in an increase of evaporation, consequently of rainfall—and thus a lowering of the temperature of the earth's surface and a cooling of the air immediately above—the surface temperature of our atmosphere can be cooler in years when the earth is receiving more heat from the sun.

Indeed, we owe our life to the fact that we live upon a wet planet. Rain, according to Dr. Hugh Robert Mill

> ... is the arterial flow pulsing from the heart of the atmosphere which carries life and power through the channels of rivers and springs over the surface and into the substance of the land. Evaporation, like the flow through the veins, brings the stream back to the heart, purified and undiminished, to begin the ceaseless round again.*

If the air were so dry that there could be no precipitation, like perhaps Venus, it would become waterless and dust-choked.†

If the cold of some future ice age should become insufferable, and what remains of mankind should make an exit by rocket to the moon, they would find the contrast terrific, for there during daylight the temperature is hotter than boiling water.

But Nature is strangely capricious in her rainfall distribution on our planet. A local summer shower involves millions of tons of air, hundreds of thousands of tons of water, and energy equivalent to the burning of thousands of tons of coal. A wide-spread storm, such as occurs along a well-marked front, involves materials and forces many hundred times greater. According to a recent estimate, some 16,000,000 tons of water pass into our atmosphere per second through evaporation and are scattered by the winds, falling as rain and snow upon the lands and oceans of the globe.

There are indications that the temperature of the world is higher at sunspot minima than at sunspot maxima; also that the earth responds to the changing condition of the sun over an interval slightly in excess of 11 years.

* *Quarterly Journal of the Royal Meteorological Society,* 53, No. 221 (January 1927), 86.

† Sir H. Spencer Jones (Astronomer Royal) "The Atmospherics of the Planets." In *Quarterly Journal of the Royal Meteorological Society,* 69, No. 295 (April 1943), 121-51.

The unequal warming of land and sea and of the air above the clouds causes wind, which carries the clouds across the face of the sky. Precipitation—moisture reaching the surface of the earth as rain, snow, hail, dew, frost, etc.—restores the water to the oceans again, where the sun starts the cycle once more in the pageant of the sky.

CHAPTER XIV

AERIAL VIEWS OF CLOUDS

SOARING IN CLOUDS AND THERMAL UPCURRENTS

Soaring, first effected in upcurrents underneath clouds, is now dependent largely on the use of thermals of heated air rising under a blue sky. Ordinarily a soaring pilot may expect a lively upflow of air below a cumulus cloud; but in the parlance of gliding, thermals are for the most part invisible currents or isolated masses of heated air which have accumulated over hot patches of ground, breaking away upwards at intervals. Thermal currents arising from conditions of instability come about through the heating of the earth's surface by the sun more in some places than in others. Where hot air ascends, its moisture condenses and forms a cloud; therefore, to keep aloft on days of instability, a glider pilot merely hops from one cloud to another. Latent heat released by the condensing moisture further increases the rate of ascent.

At a front, warm air rising over cold air results in the formation of massive clouds which cover a wide area; it is therefore possible to soar in the upward currents associated with fronts. Cross-country journeys of hundreds of miles can be accomplished in this manner.

Wind thermals and trailing "air-rollers" are terms recognized through the efforts of Wolf Hirth. Wind thermals are caused not alone by solar radiation, but also by the movement of warm air masses, moist and unstable, which form during winds of great velocity into long rolls of air with their axes in the direction of the wind. A region of powerful upcurrents exists in the rising portion of the so-called "air-rollers"—upcurrents which can usually be recognized by a long cloud street.

Moreover, special and localized conditions may exist favorable to flights such as those of the Helm wind * over the Pennines in northern England. The phenomenon occurs where the Pennine chain forms a steep

* G. Manley, "The Helm Wind." In *Quarterly Journal of the Royal Meteorological Society,* 65, No. 282 (October 1939), 505-10. See also "Discussion on Soaring Flight, *Ibid.,* 69, No. 300 (April 1943), 115-35.

southwesterly slope running northwest-southeast for some ten or more miles with an average descent of 2,000 feet.

Evidence of such conditions, with lift ceasing ostensibly at about 12,000 feet, exists in a roll or series of rolls of cloud overhanging the crest of a wave or waves to leeward of the hills when a wind from the northeast blows over the northern Pennines, ascending the gradual eastern slope and rushing down the other. As a rule, winds blowing over the tops of hills or mountains create eddy currents or downdrafts sometimes present on the leeward side of a mountain. A shallow breeze moving upslope in mountainous regions constitutes the Valley Wind.

CLOUDS IN FLIGHT—by Peter E. Kraght

An earth-view of clouds is a limited one in which only the base of the cloud and some parts of the sidewalls can be observed. To those who fly this is more clearly apparent because they have an opportunity to see the summits and sidewalls from above. Airmen have the closest perspective on clouds; and the knowledge of cloud forms and characteristics gives them invaluable assistance in navigating the unstable elements. For example, stratocumulus viewed from the top appear in many instances like a vast ocean of wavelets, with here and there a mountainlike dome protruding. Chasms and ravines on the sides and top of a towering cumulus are awe-inspiring, and pleasure flights up and down the cumulus valleys are more exciting than mountain climbing. Dodging cumulus tufts on a fair-weather afternoon is another interesting game. Flying above a dust storm is perhaps the most interesting "on-top" experience of all. With unlimited forward visibility, and none downward, the dust top looks like a wide plowed field upon which one could step from the aircraft onto firm footing.

FLIGHT ALTITUDES: Clouds are useful in selecting favorable flight altitudes, and thus are aids toward safety in flying. The absence or presence of the following factors makes the difference between safe, pleasant flight or hazardous ones: (1) icing in clouds, (2) thunderstorms on a flight track, (3) low ceilings en route and at terminals, (4) restricted surface visibilities en route and at terminals, (5) winds at cruising levels, and (6) rough air, or turbulence. The first four of these factors are directly related to clouds; the last two are often indicated by types and movements of clouds.

ICING IN CLOUDS: Icing in clouds may be a nuisance or a hazard, depending somewhat upon the type of aircraft and the kind of icing present, as well as the available de-icing equipment. Large multi-engined transports equipped with modern de-icing mechanisms can dismiss as a mere nuisance icing which the pilot of a small single-engined two-place craft would recognize as severe.

There are two distinct types of aircraft ice: clear, translucent crystalline ice and opaque noncrystalline rime. The two types are usually encountered in a mixture in which one or the other predominates; occasionally, however, they will be equal in amount. Near-freezing temperatures and large water droplets favor the formation of clear ice; low temperatures and small water droplets produce the opaque rime.

Stratus or stratified clouds are normally composed of relatively small droplets, and therefore tend to cause rime ice rather than clear. At very low temperatures they produce all rime with no clear ice. For the average aircraft, icing in stratus is usually light, occasionally moderate.

Cumulus clouds, being composed of relatively large droplets, tend to cause clear ice, especially at temperatures just below 32° F. At very low temperatures, however, cumulus can cause an accumulation almost entirely of rime ice. Icing in cumulus is moderate to severe.

Stratocumulus assume the properties of both stratus and cumulus. Sometimes they are more like stratus, sometimes more like cumulus. In these clouds, too, icing assumes the characteristics of icing in stratus or cumulus, whichever the stratocumulus most resembles.

Because they are composed of ice crystals as a rule, cirrus do not produce icing.

Within the general principles outlined, all water-droplet clouds whose temperatures is 32° F. or below should be regarded as a potential icing hazard. Rain falling into a layer of air whose temperature is 32° F. or below is also to be regarded as a region of severe icing, in which the icing is likely to be predominately clear. Sleet—frozen rain—does not cause icing, but it indicates some layer above in which rain is freezing.

Thunderstorms, also recognized as a species of cumulonimbus cloud, are the result of violent vertical air currents. The distinction between a cumulonimbus and a thunderstorm lies in the presence of electrical discharge in the latter. All cumulus clouds contain vertical air currents, but only violent ones in towering cumulus and shower-type cumulonimbus and exceedingly violent ones in the thunderstorm. It is a good policy in safe flying to avoid towering cumulus on account of these vertical currents. It is best to fly over or around them, or to land at a suitable airport and wait for the storm to pass.

If for any reason it is necessary to fly through a cumulonimbus, a flight plan should be based on these recognized principles:

1. Flight below the cloud may encounter very rough air, strong vertical currents, heavy rain, hail, and the possibility of lightning strike.

2. Flight into a greenish or off-color region may be accompanied by severe turbulence and lightning strike, heavy rain or hail. Some strong vertical currents are also possible.

3. Flight into a black part of the storm is usually accompanied by considerable turbulence, some strong vertical currents, and less likelihood of hail or lightning strike.

4. Flight just below the freezing level is likely to be accompanied by lightning strike.

5. Flight above the freezing level will be accompanied by moderate or heavy icing.

6. Flight into a thin-looking part of the cloud may be a channel through to the other side, but sometimes leads into a dead end with storm all around. A channel may also close behind the aircraft.

7. A wide break in the cloud, with clear sky or landscape showing, is usually a safe cloud-canyon through which to fly.

A cold front or prefrontal line squall, as well as a line of contiguous orographical thunderstorms, should be avoided whenever possible. They are dangerous!

LOW CEILINGS: Low ceilings are usually associated with stratus, low-lying stratocumulus, and cumulonimbus where the terrain is flat and where the clouds appear over water. High terrain may cause a low ceiling under almost any type of cloud. Extensive areas of low ceiling are normally associated with stratus and stratocumulus; whereas local areas of low ceiling are associated with cumulonimbus, patches of stratus and stratocumulus, or with irregular high terrain. Contact flights below a low-hanging cloud, even over comparatively small areas, where the terrain is irregular or its nature not fully known to the pilot, are not in line with safe flying. Possibility of the ceiling's becoming zero is always too great.

"On-top" flights over areas of low ceiling are safe, provided it does not become necessary to land under emergency conditions owing to mechanical failure. Very low ceilings at terminals where descent from on top is made are also a hazard unless the pilot can be certain of his position at all times.

RESTRICTED SURFACE VISIBILITIES: In the main, restricted surface visibility is caused by fog, but over more limited areas it may be produced by smoke and dust. Heights of ground in mountainous areas are often foggy when the valleys have good visibility and ample ceilings. Fog, smoke, and dust do not give sufficient visibility for proper handling of an aircraft during take-off and landing operations. It is therefore mandatory that no aircraft attempt to leave or enter an airport where visibility is highly restricted. Likewise an emergency landing in thick fog is most hazardous.

WINDS AT CRUISING LEVELS: These winds are not dependent upon clouds, but clouds drifting with them indicate in a way their direction and velocity. Cumulus at 4,000 feet drifting from WSW at an estimated 25 mph indicate that in the air layer from 3,000 feet to 5,000 feet the wind to be expected will be from about 250° at 25 mph. All clouds having definite shadows which can be followed with the naked eye or with an instrument, indicate the approximate wind at their level. Winds well below or above a cloud sheet cannot be determined in this manner.

ROUGH AIR: The air is rough when vertical currents occur in a layer of air. Normally a layer of rough air is bounded by the earth's surface and an inversion at some distance up; but a rough layer is sometimes sandwiched in between two layers of smooth air well above the earth. Rough air is frequently found in the absence of clouds because the rising air currents are too dry to produce clouds.

On the other hand, certain clouds indicate rough flying by their presence. Flat fair-weather cumulus indicate roughness below the level of the cloud base and inside the clouds themselves. Towering preshower or prethunderstorm cumulus are a sign of considerable roughness within the cloud and the usual roughness below the cloud base. Cumulonimbus indicate excessive roughness inside and directly below the cloud, as well as the usual roughness elsewhere below the level of the cloud base. Cumulus form in vertical currents and always indicate some degree of roughness of flying air.

Stratocumulus show considerable roughness in and below the cloud; but it depends upon the degree to which the cloud layer has the characteristics of cumulus. Stratus is a sign of smooth air. Fog and restricted surface visibility are also indications of smooth air. Immediately above an inversion smooth air is always to be found, although mild updrafts may be present. It is also normally present directly above a layer of flat cumulus or stratocumulus.

Those days when there are few clouds, the air is smooth and relatively dry, and the visibility is unrestricted are the prize flying days. They are the private flier's field days.

Official Photograph, U. S. Army Air Forc

CLEARING SKIES AT DAWN. An army basic-training plane is silhouetted against clearing skies, ready to take student fliers aloft at Moffett Field, in California. Earth and clouds take on new shapes and and colors for the flier. As he rises through the morning gray of a valley and sees the sun's ball flame suddenly above a mountain ridge, he has a sense of beholding the dawn of creation. Reddish mist steams up from distant valleys and disperses in the morning breeze. While mountains glide and float in titanic motion, the clouds of the eastern sky hang like a second mountain chain of still more fiery light.

The pictures in this section show a few of the ever-changing cloud patterns as a pilot sees them from above.

Official Photograph, U. S. Army Air Forces

A VALLEY OF CLOUDS. Stratocumulus or altocumulus, photographed from an altitude of about a mile, with heavy and swelling cumulus below the stratocumulus. An observer near the massive heaped-up cloud forms to the right would call them stratocumulus. Someone farther away—at sea level, for instance, would label them altocumulus. The billowy towering masses, seen at close range here, are produced by vertical convection movements; hence they form when heat from the earth warms the air, and they vanish at night with the sun. They gather in an area of rising moist air and usually hang at about 2 to 2½ miles high. The turbulence of the wind plays an important part in carrying water vapor, heat, and dust to the level of these clouds. When they mark the front of an arriving wedge of cold air, they may develop thunderstorms locally.

Photo by Pan American Airways Syste

EXPECT UNSETTLED CONDITIONS AT INTERMEDIATE LEVELS.

The combination of cumulus and altocumulus indicates internal motion and turbulence. Increasing altostratus is usually followed by continuous and lasting precipitation.

When, as in the background of the picture above, altocumulus appear in a double-wave formation rather than in detached globular masses, the indications are more unsettled conditions in the intermediate levels of the atmosphere.

Flying over the tops of thunderclouds, billowy or anviled, exposes an aircraft to the risk of being struck by lightning since a discharge will employ any object in its path as a conductor superior to the partially ionized air. Most lightning strikes upon aircraft, however, occur close to or somewhat below the freezing level. Rain or snow adds to the probability of a lightning strike, and a high degree of humidity is favorable to a dangerous storm.

Photo by H. B. Wyatt, Naval Air Station, San Diego

CUMULONIMBUS SEEN FROM THE AIR. This excellent photograph shows three huge turreted cumulonimbus clouds. Their tops are transformed into a cirrus mass; to the left, cirrus is breaking off into higher levels. The characteristic flat base shows up unusually well, and also the building up of the clouds as warm, moist air is pushed upward when air slides in beneath and moisture condenses.

It is dangerous for aircraft to fly between the towers of two adjacent cumulus clouds, as well as over the tops. Safety lies in flying around the cloud, on the same principle as keeping clear of cumulus clouds whose temperatures are below freezing to avoid the hazards of icing. Propellers of aircraft flying near thunderstorms may develop St. Elmo's Fire—a brush discharge from a charged object.

Photo by American Airlines, In

CUMULUS IN PROCESS OF GROWTH. These beautiful cloud formations high over the distant countryside are the kind which a flier may see at about 7,000 feet. They may remain as they are, along with fine weather, or may develop into a thunderstorm. Cumulus are more turbulent over land than over water, and updraft velocities within any one cumulus cloud increases with height. Because of strong up-currents, cumulonimbus are dangerous to fly in at any altitude, but planes can pass under them with safety over flat country or over water. The most severe turbulence and the strongest vertical velocities, both hazardous to flight, are found in the upper two-thirds of a cumulonimbus. Vertical velocities are least along the edges or below the base of the cloud, assuming its base to be about 2,000 feet above the earth's surface.

Photo by American Airlines, Inc.

SWELLING CUMULUS. This exceptionally close view of cumulus, as though the observer were flying through it, shows up the following:

1. The edges of the cloud surface are well defined and compact.
2. The anvil to the left is beginning to overshadow the observer.
3. The vertical development is very great.
4. The structure is nonfibrous, or cauliflower, brightly illuminated.
5. The cloud interior—to the left—indicates marked turbulence caused by ascending and descending air currents.

Like cumulonimbus, this heavy, swelling cumulus is formed either in calms, especially on very warm thundery days, or in a strong wind in the rear of disturbances.

Photo by American Airlines, Inc.

RAGGED CUMULUS, appearing at wing tip, with edges of cumulus building up on the right. The dark haze in the background is about 60 miles from the cloudbank the plane is entering.

Courtesy, U. S. Weather Bureau

EARLY-AFTERNOON CUMULUS, the most frequent type of low clouds. The fleecy cumulus of fine weather come behind a cold front in a cold air mass.

Official Photograph, U. S. Army Air Forces

CUMULIFORM MASSES, in waves so close that their edges touch. The faint upper layer indicates a background of undulated altocumulus.

Photo by Transcontinental and Western Airlines, Inc.

CUMULUS AND ALTOCUMULUS, over San Gorgonia Pass, California. The bubbling tops show the intensity of the energy being released. The light cirrus are mare's-tails, harbingers of wet weather.

Official Photograph, U. S. Army Air Forces

A PEEP-HOLE IN THE CLOUDS. Imperfections level out and only beauty remains when the earth is viewed from a peep-hole in the clouds.

Photo by Pan American Airways System

MANY CLOUD FORMS. Cumulonimbus and altostratus in rolls; in the foreground isolated masses of fractocumulus. Photographed from the Hawaiian Clipper at 8,000 feet, June 1938.

Photo by American Airlines, Inc.

CUMULUS AND ALTOSTRATUS. Scattered ragged cumulus in the foreground, with a scattered altostratus sheet in the background, usually encountered above 9,000 feet.

Courtesy, U. S. Weather Bureau

CUMULUS AND STRATOCUMULUS. The cumulus, upper surface, are fairly close to each other, and in some parts closely packed.

Photo by Hans Groenhoff

CHET DECKER'S "ALBATROSS." Soaring over Warren Eaton Field in Elmira, New York. The pilot of a glider is on the alert for warm, moist southerly winds with underrunning cold, dry northwest winds. Local heating, topographic irregularities, and buildings are the principal sources of gustiness. Convection is most active on summer afternoons, particularly in the neighborhood of cumulus and altocumulus clouds like those above. Local heating is greater over a black soil than over a light one; greater above a plowed field than over sod; and greater over land than over water. The consequent changes in density of the air give rise to vigorous convection which produces a bodily uplift or drop of the glider. Cases are on record of vertical movements of 3 to 4 meters per second. At Blue Hill Observatory one of 7 mph was observed.

Photo by A. Hoeflich; Courtesy, Northern California Soaring Society

THE "GRUNAU," flown by Sanborn and Atherton. Cumulus, strato-cumulus, fractocumulus, and altocumulus in the middle distance. The sky overhead indicates turbulence and advancing instability in the lower air.

TABLE OF EQUIVALENTS

Length

1 meter = 39.37 inches, or 3.281 feet

1 kilometer = 0.621 mile, or 3281 feet

1 mile = 1.61 kilometers or 1610 meters

Approximate Equivalents

106 meters = 348 feet

948 meters = 3112 feet

2,955 meters = 9,700 feet

4,186 meters = 13,740 feet

Weight

1 lb. = 453.6 grams

1 lb. = 7,000 grains

1 lb. = 0.453 kilograms

1 kilogram = 2.2 lb.

Pressure

1 inch mercury = 25.4 millimeters —33

1 millimeter mercury = 0.03937 inch—1,3332

1 millibar-0.02953 = 0.75006 millimeter

27 inches = 914.3 millibars

28 inches = 948.2 millibars

28.5 inches = 965.1 millibars

29 inches = 982.1 millibars

29.5 inches = 999 millibars

29.75 inches = 1,007.5 millibars

29.92 * inches = 1,013.2 millibars

30 inches = 1,015.9 millibars

30.25 inches = 1,024.4 millibars

TEMPERATURE: All upper-air measurements are made in degrees Centigrade. Fahrenheit degrees are used on the surface weather map.

	Degrees Fahrenheit	Degrees Centigrade
Water boils at	212	100
Water freezes at	32	0
Absolute zero temperature	—460	—273

One Centigrade degree = 1.8 times one Fahrenheit degree
One Fahrenheit degree = 0.55 of one Centigrade degree
Nine Fahrenheit degrees = five Centigrade degrees

400° above zero C. = 752° above zero F.

200° below zero C. = 328° below zero F.

Potential temperature is the temperature that a specimen of air or other gas would assume if brought adiabatically to a standard pressure, now usually selected as 1,000 millibars.

Pressure

a bar is a unit of pressure equal to 1,000,000 dynes per square centimeter

1 bar = 100 centibars = 1,000 millibars

a barometric pressure of 1 bar is sometimes called a "C. G. S. atmosphere," and equals a pressure of 29.531 inches of mercury at 32° F. and in latitude 45°.

* Pressure of 1 standard atmosphere 0.04 inch (1.35 millibars); 0.15 inch (5.08 millibars); 1.5 inches (50 millibars).

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